CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

A TECHNICAL JOURNAL FOR DESIGNERS AND USERS OF ELECTRICAL, ELECTRONIC, HYDRAULIC, MECHANICAL AND PNEUMATIC CONTROL SYSTEMS AND INSTRUMENTATION

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Barry Gibbs
18 Grangeway, Handforth, Cheshire
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Box 206, Essex, Conn. *tel:* South 7-1838

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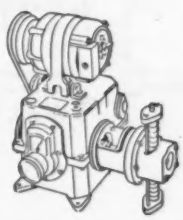

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CONTROL

PUBLISHERS COLUMN

PERCY STREET VIEWPOINT

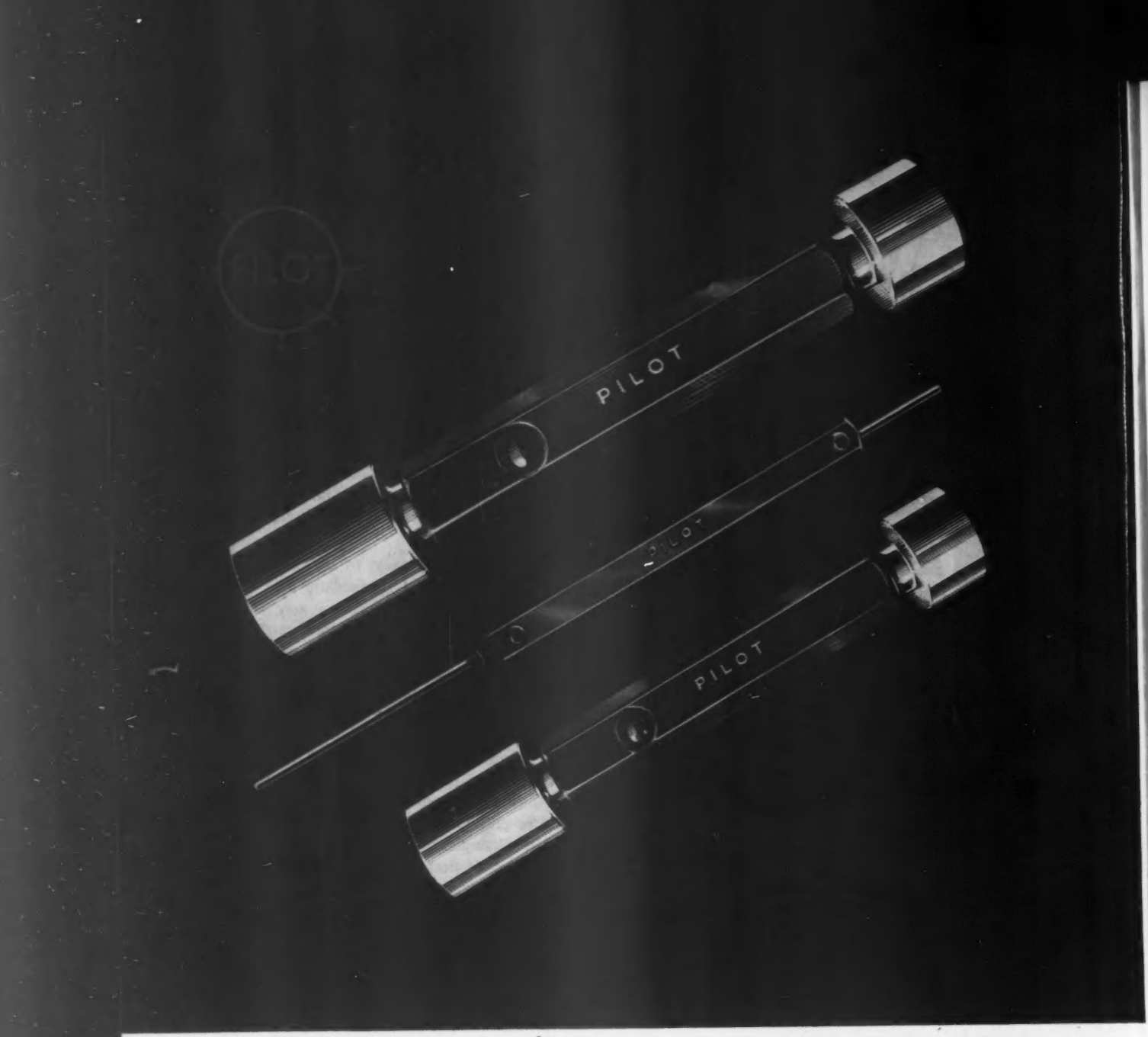
The foot of CONTROL's contents page—inside the front cover—gives our address: 3 Percy Street, London, W1. Our offices are in fact in North Soho, near Oxford Street to the south and Tottenham Court Road to the east. If you are visiting us by Tube come to Tottenham Court Road or Goodge Street station.

We are always pleased to see or hear from you the reader, particularly if you have a problem over which we may be able to help, an idea which others might like to use, or indeed a suggestion which you feel will make CONTROL of greater value to you. If you would like further details of any product mentioned in CONTROL, or if you wish to comment on or criticize any article or feature, please write to, or call upon, the Editor. He and his staff—or if need be our consultants—will be only too pleased to help.

For example, two engineers from a large aircraft firm who wished to know more about customers' requirements for industrial instrumentation visited us early this month. Another visitor was having trouble finding a manufacturer for an unusual instrument he had patented, and we were able to introduce him to several likely firms.

We receive many individual inquiries of this nature but the more straightforward problems are handled by our Reader Information Service. Hundreds, and sometimes thousands, of requests for further information on particular instruments or equipments mentioned in CONTROL's columns are dealt with each month. Normally these merely entail putting readers in touch with the manufacturers or organizations concerned, but occasionally an apparently routine request for further information will put us on the track of something of general control engineering interest.

You know our address: please write or make an appointment to see us if you have an instrumentation or control problem.



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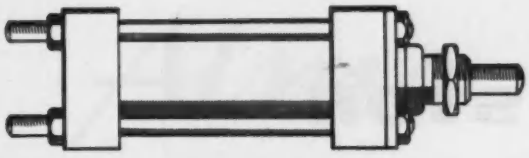

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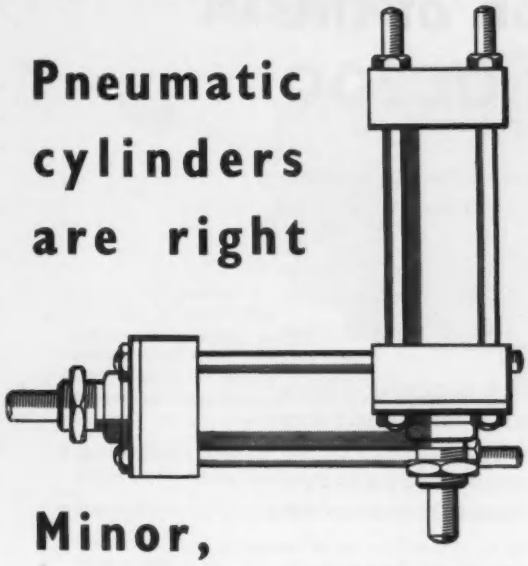

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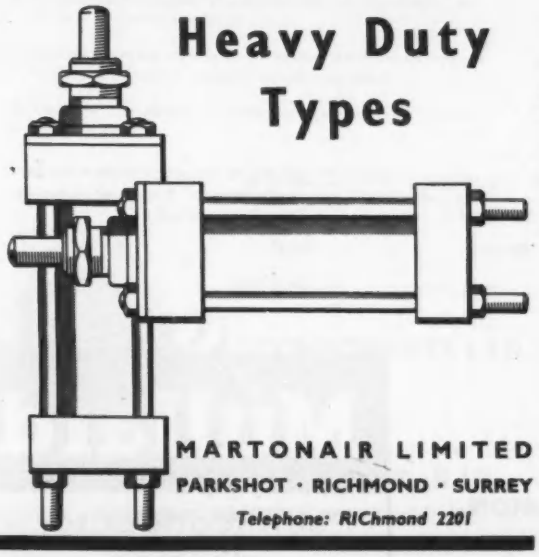

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Sir!

The Editor welcomes correspondence for publication.

Past simplicity

SIR: On looking through the pages of your excellent magazine, it occurred to me that in these days of rapid, almost phenomenal advances in instrumentation it would be a good thing to look backwards occasionally. I feel that this exercise would give a number of engineers a surprise.

In this age of atomic piles, electronic brains and the like, a void has developed behind us—a void in which many simpler types of controller, older in principle than most of us, have been woefully overlooked, to the detriment of all.

For example, the old bi-metallic on/off controller, suitably employed under favourable conditions, can still produce some remarkable results.

Beeston E. EMMERSON

● *'Men care most for the newest air that hovers on the singer's lips.' Yet engineering advances are often made by digging up an almost forgotten device and improving it, e.g. the transistor owes something to the catswhisker and crystal, the digital computer to Babbage's calculating engine. But surely, with the numerous thermostats fitted today, the bimetallic on/off controller cannot be counted as being in oblivion? Possibly windmills—one of the earliest examples of control engineering—are ripe for a revival: indeed the Electrical Research Association have for the last ten years been successfully experimenting with them as sources of power generation. The response of the CEGB and other supply authorities may not have been as enthusiastic as was expected at one time, but they have by no means lost interest in windmills—particularly for local generation on islands.*—EDITOR.

Model men

SIR: I am an operational research worker who has recently discussed with a control engineer methods of approach and analysis in our respective fields of work. It seems to me that in the initial stages at any rate the principles involved are identical though the 'problem areas' might be different. Both in operational research and in control engineering the projects, and the terms of reference, are such that the investigator cannot concern himself overmuch with the fundamental relations which make up the system (though these are, of course, helpful if they are known); he must 'simulate' the system in order to learn how it behaves. From then on the analyses may differ since the o.r. man will be using his 'model' to see the effects of making changes in the system under study, whereas the control engineer will be studying the effects of different forms of control.

The models used will probably be similar, namely, mathematical, statistical, or Monte-Carlo-type simulation, and this implies a knowledge of the appropriate analytical techniques as well as an understanding of this approach to the study of systems.

Am I right in thinking this, or does the control engineer come in after the initial stages of the analysis (and if so, who does the initial bit?).

ORBIT (Operational Research) Ltd. J. BANBURY

● *We view it like this. The control engineer tackles more limited problems than the o.r. man, but he has to find more accurate solutions. Moreover his problems are primarily technical—usually the o.r. man's are primarily economic. Again, as pointed out at the recent symposium on instrumentation and computation in process plant, the o.r. man deals with human beings much more than the control engineer.*—EDITOR

continued on page 61

SILICON ALLOY TRANSISTOR OC201

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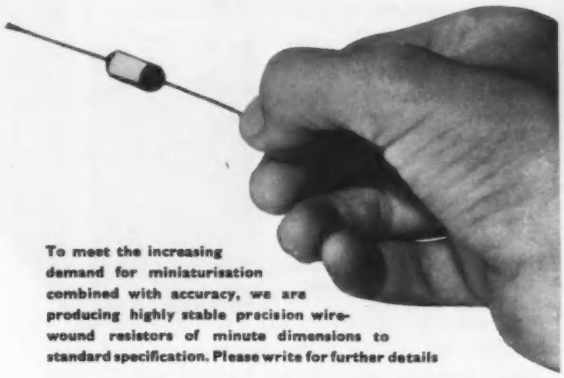

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Continued from page 59

Sir!

Wrong missile jargon ?

SIR: Mr. M. D. Hull complains in your April issue of incorrect and unapproved terminology, and doubtful meanings in a guided missile glossary for which I was responsible. While I sympathize with his anxiety I cannot accept his accusations lightly. Presumably he is being employed by the Ministry of Supply to provide a list of g.w. definitions which, it is hoped, will be acceptable to those interested in contract procedure. On the other hand, my terms of reference are rather wider, for I am explaining engineering aspects both to students, and more recently to readers of CONTROL who may have no previous idea about the terminology. My definitions will stand the test of accuracy, and will be acceptable to missile men who have been in the business since its conception. That the aircraft industry has been in the forefront of this new and developing technology is no case for damning the terms which are used; and let's face it, missiles do fly. Let Mr. Hull beware of this proposed breakaway from aircraft terms. Already the Americans are producing research aircraft of near-missile performance. Are we to have two dictionaries and two breeds of engineers because one airframe is manned and the other is not?

In Mr. Hull's subsequent letter, published in the May issue, he has provided some OFFICIAL DEFINITIONS, for which I am most grateful. Being a good citizen I will use them when communicating with the Ministry. Nevertheless I wish to put on record that I cannot accept Mr. Hull's thesis of a 'Ministry approved' terminology to the exclusion of all else.

Cranfield K. C. GARNER

For the record

SIR: We have read with great interest the valuable survey of Potentiometric Recorders by Mr. C. W. Munday, published in your February issue. However in one or two places the information was out-of-date or incomplete.

The Cambridge Electronic Recorder can record on up to 12 channels as a dotting instrument, and as an in-line scanner it can measure sequentially up to 400 points. The figure given for accuracy (±0·5%) is not the best figure for the range, as might be inferred, but a minimum one, true of all ranges of the recorder down to 1 mV full scale.

The Cambridge quick-acting recorder is normally supplied with a multi-speed gearbox giving 6 speeds from ¼ to 6 in/min, but speeds of up to 120 in/min can be provided to special order. In the multi-channel version these recorders can dot as fast as one point every 1·5 sec.

Cambridge Instrument Co. R. K. SHEPHERD

Stimulating stuff—but less than proof

SIR: I have been reading the series of articles 'Making Aircraft Systems Work' by Messrs Foody and Mills of Short Bros & Harland, which appeared in the February, March and April issues of CONTROL.

Although I cannot go all the way with them, I must admit that I found their ideas stimulating. They appear to be very much wedded to the simulator approach and I suspect there is now too great a tendency to believe the analogue computer capable of overcoming all our problems. The use of a simulator must save some money, but I doubt if it will decrease the number of flying hours significantly. After all, an aircraft control system can only be proved in the air, and an unlimited amount of simulation cannot affect flight proving. I am afraid that many of the older breed of aircraft engineers will be loath to lose any of their hard-won flight testing, simulation or not.

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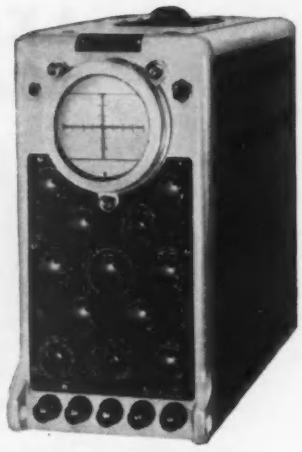

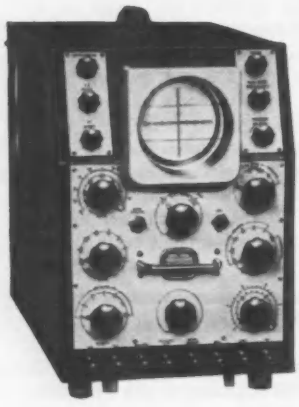

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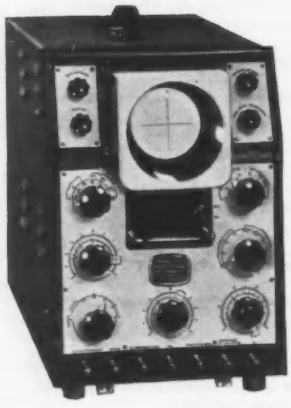

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CONTROL JUNE 1959 VOL 2 NO 12

Lagging or Leading?

IS 'FULL AUTOMATION' BEING INTRODUCED INTO British industry fast enough? Clearly certain people feel it is not. Articles with this theme have appeared in the national Press; engineers returning from Russia have pointed to the prodigious efforts being made to speed the development of both the theory and practice of control engineering in the Soviet Union; there is talk of the danger of Britain being 'out-automated' in export markets; CONTROL itself has contrasted the blaze of publicity for automation a few years ago and the paucity of installations in manufacturing industry since.

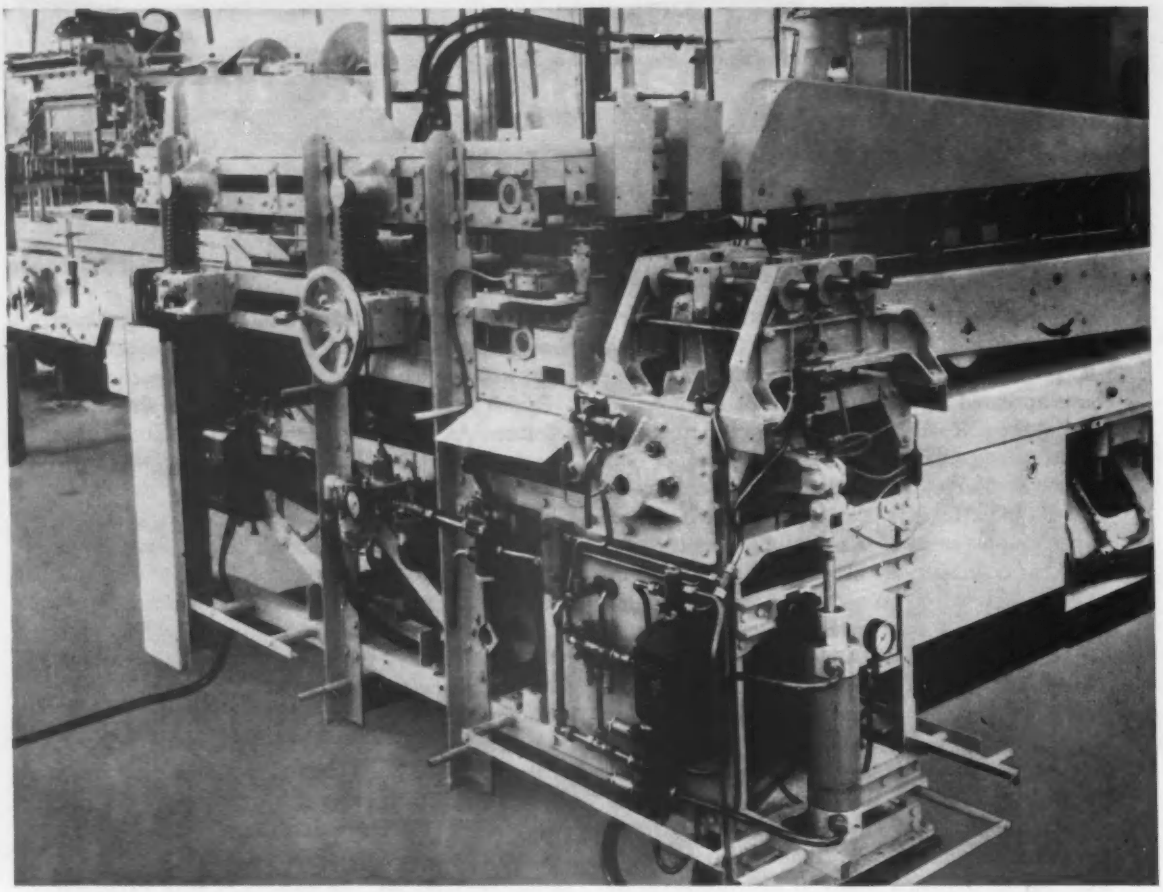
The President of SIMA, Mr. Barrington-Brock, disagrees. In a speech at the Association's Annual Luncheon last month, he said he believed that Britain was not lagging on other countries in this matter; and that big British industrial firms were ready to use 'full automation' when it became economic to do so. We much respect Mr. Barrington-Brock's opinions on instrumentation and control, but in our view many British industrialists have not yet grasped the changed economic conditions which embrace these islands, and the resulting need to lead other countries in productive efficiency.

One can of course quote individual examples of advanced industrial control from different industries and countries to support one's own belief. The sprinters in most countries are ahead of the plodders in others. British engineers in the chemical industry may tell you—with much truth—that it is nonsense to talk about the USA being ahead of Britain in process control development. Yet several recent reports contend that the Americans have a lead over us both generally and in particular industries. Thus the introduction to the DSIR report on 'Automation in North America,' published last year, begins: 'Progress with automation has been much more rapid in North America than in the United Kingdom'. Again, the recently issued annual report of BISRA avers that 'Remote position control of screwdown has reached an advanced stage of development in the USA and is accepted as an essential requirement in many mills. The Americans are ahead of this country in the application of automation to rolling-mills'.

The question is patently subjective and, in respect of exporting competitors such as Germany, Japan and Sweden, has not yet had any chance of resolution by commercial test. But more significant at present than an answer to this lag-lead question is the attitude of the British public and particularly British industrialists. For this attitude shapes the future. As Mr. Barrington-Brock indicates, the economics of installing automatic equipment are all-important; but unless firms can think ahead they will not be ready when the economic hour strikes. Then Britain will find herself falling back in the commercial cross-country races she has now entered in several parts of the world. Full benefit from 'full automation' demands a willingness to rethink office and factory procedures—which takes time.

It is in their approach to automation, in their readiness to probe new concepts and techniques, we believe, that some other competing countries have the edge on Britain. The outlook of many responsible Britons was all too well epitomized by the House of Commons debate on the consequences of automation last month, when, as the *Manchester Guardian* reported, 'for most of its hour's run, the automation debate provided us with the extraordinary sight . . . of one of the most able of Ministers, dealing with one of the most vital of topics, sitting entirely alone, the duty Whip apart, on the Government benches. The Opposition . . . did substantially better, with five rising to seven'. Nine out of 630. Yet the maintenance of British life as we know it will depend on our leaders learning the right answers to the type of question under discussion. So far automation has had about as much impact on these islands as the Romans achieved in 55 BC: much more was to follow.

In that debate the Minister of Labour said, 'I have no desire to become Minister of Automation. We do not do things in that way in this country.' Maybe so, but if the creation of such a post would provide an effective lead for speeding the introduction of automatic control it would be welcome. No one knows whether the Board of Trade, the Ministry of Supply, the Ministry of Labour or the DSIR is prime mover in this vital matter. Each has dabbled in it. The Government should make one Minister responsible for automation, and then give him the means to bring home to industrialists—and to the public at large—the economic urgency of rapid industrial acceptance of new control and computing techniques.



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'Why not British?' asked John Fielden
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General Manager of British
Arca Regulators says

It's us or US

'WE TAKE YOUR IDEAS AND RUN LIKE HELL WITH them'. This frank statement from a visiting American industrialist provides the complete answer to the question recently posed on this page, 'Why not British?'*

In research and development, the British instrument industry is well able to hold its own, but, when it comes to converting the 'bread board' model into a fully-engineered production design, we are very long-winded; in fact some of us never get there at all.

Two main reasons lie at the root of the trouble: first, there are too many companies making too many variations of the same thing; secondly, there is not only a noticeable shortage of production engineers in the instrument industry, but also a shortage of managements who understand the need for production engineers. How many top managements really know the difference between a production engineer and a production manager?

Fundamentally these two causes stem from one basic failing—by no means confined to the instrument industry alone—the absence of accurate up-to-date cost information. Anyone with personal experience of American industry will confirm that although production efficiency is generally of a very high standard, what keeps it at its peak is the cost accounting which is used as a tool by efficient management.

How many of us really know which of our products make the most profit, and which the least, or indeed a loss? And of those who do, how many get the information in time to do something with it?

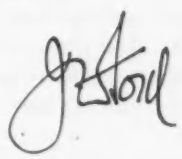
From the industry's point of view then, we need a new approach to production engineering and cost accounting, and fresh emphasis on variety reduction.

What of the customer? Here again there is a basic difference of outlook on the two sides of the Atlantic: the American is much more willing to try something new, to run tests, to evaluate a new product or a new system scientifically.

Over here the tendency is to let someone else do it and wait for his opinion. I well remember showing a very senior official a new American control system, beautifully designed, superbly engineered and competitive in price. His first comment: 'Of course, *I* still drive a car with a walnut fascia'.

Here let me say that my own company does not manufacture anything under American licence, but that I see absolutely nothing against it, providing at the same time that one continues one's own fundamental research and development and does not come to rely solely on purchased ideas.

Wishful thinking will not put us in the lead again, we need solid results. Control engineering is only just beginning; there will be a world wide market for the efficient producers.



We apologize to readers for the late publication of this issue owing to the printing dispute. We have had, at the last minute, to reduce the scheduled number of editorial and advertising pages and we regret that certain items listed on the Contents page are therefore not included.

*Industry's Viewpoint by J. E. Fielden, Founder and Chairman of Fielden Electronics, December 1958.

PART 1

Radar and computers help the control of freight trains in British Railways' latest marshalling yards

by **J. F. H. TYLER**

Signal Engineer, Southern Region, British Railways; formerly Assistant Signal Engineering Officer, British Railways Division of the British Transport Commission

Automatic marshalling of railway wagons

THE NEED FOR FREIGHT TRAINS TO BE RE-MARSHALLED in the course of transporting goods from one part of a railway system to another may be illustrated by the following example. Suppose it is necessary to carry freight a distance of x miles from A, B and C to D, E and F. If the service is direct (Fig. 1a), 9 trains will be required, each travelling x miles. If the trains are passed through a marshalling yard *en route* (Fig. 1b), the number of train movements is reduced to 6 and the train-miles to $6x$. If there are two marshalling yards, say $x/3$ miles apart (Fig. 1c), there will be 7 train movements but the number of train-miles will be reduced to $2{\cdot}33x$. On average, the marshalling yards will be closer than $x/3$ to the starting and finishing points and the saving in train-miles will, in fact, be better than in the example.

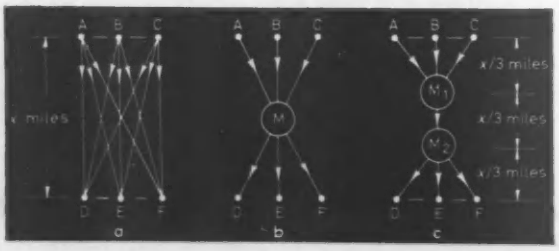
Yards must be sited strategically

To keep freight train-miles to an economic minimum, one must locate marshalling yards at strategic points in the railway system through which flows of traffic can be directed. The capacity of a marshalling yard, and therefore its size, depend on the number of wagons to be dealt with per day.

On British Railways, innumerable marshalling yards of all sizes exist, including a number of large mechanized yards and the policy under the modernization plan is to concentrate the work of the smaller yards into yards of this type wherever it is economical to do so. Fig. 2 shows a typical scheme and gives some idea of the number of wagons marshalled daily at a fairly large yard.

Fig. 1 Illustrating the need to marshal wagons in freight trains. Each arrow represents one train.

a Train-miles=9x. **b** Train-miles=6x. **c** Train-miles=2·33x.



Yard layout

A modern marshalling yard consists essentially of:

- **a.** Reception sidings in which incoming trains are held to await marshalling.
- **b.** A 'hump' in the track formation which produces the steep gradient to enable wagons to gravitate into the marshalling sidings.
- **c.** The switching zone in which are situated the power-operated points leading into the marshalling sidings.
- **d.** Retarders which reduce the gravitating speed of the wagons as required to avoid heavy collisions.
- **e.** Marshalling sidings, each corresponding to a particular destination, into which the wagons are directed and
- **f.** Departure sidings, in which outgoing trains are held awaiting departure.

The marshalling yard is situated alongside the running lines to which it must be connected at each end. Other connexions are necessary if the yard is designed to deal with traffic moving in both directions along the running lines. The essentials are shown in Fig. 3.

Separating the wagon 'cuts'

The incoming train enters one of the reception sidings where the locomotive is uncoupled and routed over the locomotive outlet line to the shed or for other duties. The destination labels on the wagons are then examined by a shunter who prepares a *cut* list showing where the train must be uncoupled for marshalling and the next destination of each cut of wagons. He also chalks, on the front of the leading wagon of each cut, the number of the marshalling siding corresponding to the destination.

Meanwhile the shunting locomotive has backed onto the rear of the train, and when the signal is given, the train is pushed over the hump at a speed of 2–3 ft/sec. As the leading wagon of each cut reaches the crest of the hump, a shunter uncouples that cut from the remainder of the train. He is assisted in this operation by

the short rising gradient approaching the hump which ensures that the coupling is slack.

The vertical curve of the track over the hump and the steep gradients which follow it ensure that the cuts are well separated as they gravitate towards the marshalling sidings.

The points in the switching zone which lead to the marshalling sidings are power-operated and controlled by track circuits. They operate automatically between the cuts of wagons to route each cut into its predetermined siding.

Primary and secondary retarders

As will be seen in detail later, the height of the hump and the gradients which follow it are such that a good running wagon will gravitate to the far end of the marshalling sidings where braking 'skids' are placed on the rails to ensure that it will run no further. As the wagons fill up the marshalling sidings, the length available becomes shorter and it is necessary to reduce the

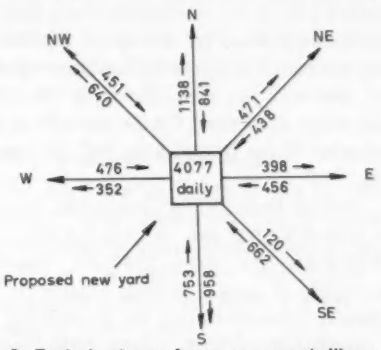


Fig. 2 Typical scheme for a new marshalling yard. The figures indicate the average daily number of wagons passing over each route

speed of the good running wagons to avoid heavy collisions which would damage or displace the load carried. This is the purpose of the retarders, two sets of which are usually provided in modern marshalling yards. The first, or primary, set of retarders (Fig. 4) is located just beyond the first set of points in the switching zone and the second, or secondary, set of retarders (Fig. 5) is placed just beyond the third set of points. The first, second and third sets of points are known as the 'king', 'queen' and 'jack' points.

The primary retarders are automatically operated and, for reasons developed later in this article, their function is to maintain adequate separation between the cuts of wagons as they pass through the switching zone. The purpose of the secondary retarders is to ensure that the wagon comes to rest immediately behind the wagon next ahead in the marshalling siding or at least does not collide heavily with it. The degree of retard-

Fig. 3 The layout of sidings in a marshalling yard

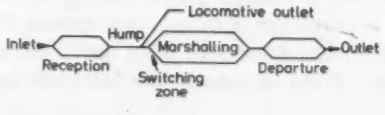


Fig. 4 Temple Mills marshalling yard: general view of the hump from the control tower, during shunting operations. A wagon is being slowed down by one of the two primary retarders

ation to be applied to a particular wagon may either be a matter for the discretion of the operator as at the new marshalling yards at Thornton (Scottish Region) and Temple Mills (Eastern Region), or it may be entirely automatic as proposed for the yards to be provided at Perth (Scottish Region) and Margam (Western Region).

When a sufficient number of wagons have been marshalled to enable trains to be formed, a shunting locomotive at the far end of the marshalling siding pushes the wagons together to enable them to be coupled. The completed train is then drawn into the departure sidings to await dispatch.

The foregoing is a simplified description of the procedure. There are a number of other tasks to be performed such as disconnecting the vacuum brake pipes on arrival at the reception sidings and releasing the brakes on each vacuum-braked wagon. After marshalling and coupling up, the vacuum brake pipes must be connected and tested. Brake pipe connexions often need changing. These operations, whilst time consuming, do not affect the principles on which a modern marshalling yard is operated. Time can be saved here only by the provision of automatic couplers which include brake pipe connexions.

Engineering considerations

The engineering considerations which underlie the design of a modern mechanized marshalling yard may be grouped under three headings, namely:

1. Dynamics of wagon movement
2. Control and operation of the retarders
3. Control and operation of the points in the switching zone

If wagons were consistent in gravitating into the marshalling sidings there would be little difficulty in retarding them so that each one stopped in exactly the position desired. Unfortunately, not only do wagons differ in their running characteristics, but also these characteristics for a particular wagon may vary during its passage into the marshalling sidings. Unless the wagons are accurately retarded damage to them and their contents may occur.

The main problem of the signal engineer designing a marshalling yard lies in coping with the inconsistent and variable running of wagons.

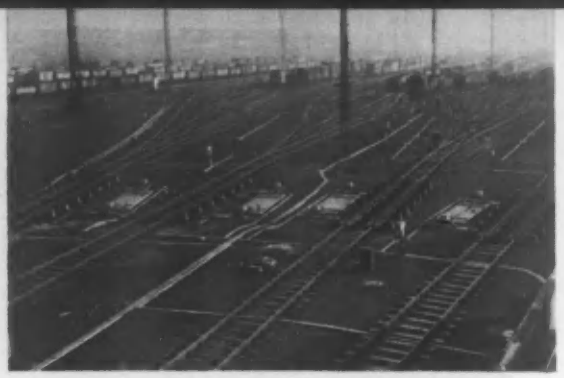


Fig. 5 Sorting sidings on one side of Temple Mills yard seen from the control tower. The secondary retarders for four fans of sidings can be seen

The dynamics of wagon movement

The total kinetic energy of a wagon moving freely at speed v ft/sec is the sum of the kinetic energy due to the total weight W lb of the wagon and its load and the kinetic energy due to the weight W_1 lb of the wheels.

$$\text{Thus kinetic energy} = \frac{Wv^2}{2g} + \frac{I\omega^2}{2g}$$

$$= \frac{Wv^2}{2g} + \frac{W_1v^2}{2g} \times \frac{k^2}{r^2} \text{ ft-lb} \quad \ldots (1)$$

where I is the moment of inertia of the wheels about the axis of rotation, ω is the angular velocity in radians per second, k is the radius of gyration of the wheels in feet, r is the radius of the wheels in feet and g is the gravitational acceleration ($= 32{\cdot}2$ ft/sec^2).

Now British wagons vary considerably in size and weight and for our purpose an average must be assumed. It has been estimated that the ratio of W_1 to W for an empty wagon is about $\frac{1}{4}$ and for a full wagon about 1/20. For British wagons, the ratio k^2/r^2 may be taken as 0·6.

Substituting in equation 1, we have

Kinetic energy $= 0{\cdot}0166v^2W$ ft-lb for empty wagons

$= 0{\cdot}016v^2W$ ft-lb for loaded wagons

or in general, kinetic energy $= Kv^2W$ ... (2)

(Note that kinetic energy $= 0{\cdot}0155v^2W^2$ if kinetic energy of wheels is ignored.)

Neglecting friction and assuming no initial velocity, we may say that the potential energy equals the kinetic energy. Thus if H is the vertical distance in feet through which the wagon has fallen in attaining a speed of v ft/sec,

$$WH = Kv^2W$$

and hence $H = Kv^2$ ... (3)

Now the resistances to forward motion on a freely gravitating wagon are the rolling resistance of the wagon itself, the resistance offered by the track and the wind resistance. The last may also be an accelerating force.

Rolling resistance

The rolling resistance of a wagon (see Fig. 6) is essentially dependent on its weight and speed and the gradient, although for practical purposes the last may be ignored. The main factors which determine rolling resistance are the journal friction, friction due to the condition of wheel flanges, friction due to non-parallel axles, friction due to brake blocks rubbing on rims, unequal loading on wheels due to position of load, etc. Another factor is the resistance due to the motion of the wagon in still air. This is proportional to the square of the speed.

Referring to Fig. 6, θ is the angle of inclination of the track at which the wagon commences to move with uniform velocity. The coefficient of wagon rolling resistance μ is

$$\frac{W\sin\theta}{W} = \frac{1}{G} \quad \ldots (4)$$

where G is the gradient (e.g. 100, for 1 in 100 or 1%).

The wagon rolling resistance may be expressed as the percentage gradient at which the wagon is just non-accelerating. For example, if the wagon is non-accelerating on a 1 in 100 gradient, its rolling resistance is said to be 1%. It will be appreciated that as the viscosity of the journal lubricating oil varies with temperature, the rolling resistance will be greater in cold weather.

The resistance offered by still air to the movement of the wagon varies not only with the square of the wagon speed but also with the area offered by the front of the wagon. Its value is affected by the turbulence caused at the boundaries of the frontal area and the underside of the wagon.

Tests confirm that rolling resistance varies widely and only typical figures can be used for the purpose of design. Unfortunately, apart from air resistance, the effect of which is small, rolling resistance does not always remain constant during the passage of a wagon into the marshalling sidings. Many tests have already been made and the British Railways Research Division at Derby is engaged on a special study of the problem. One must also bear in mind that wind resistance to a single wagon is different from that offered to a cut of wagons.

Track and wind resistance

Track resistance is also a factor which is important. It arises on straight track from the condition of the rail, the packing and the state of maintenance of the rail joints. On curved track, the side thrust of the wagon increases the flange resistance, and the switch rails, apart from their curvature, also introduce variations in resistance.

Wind resistance varies according to the wagon speed and the wind speed and the angle at which it strikes the wagon or cut of wagons. Wind pressure having a forward component results in an accelerating force which may increase the speed beyond the designed maximum.

In these circumstances, precise design calculations are impossible although certain provisions can be made to reduce rolling resistance. Roller-bearing axle boxes result in a significant decrease and certain classes of wagon are being fitted with them under the modernization plan. Wind screens in the form of high paling

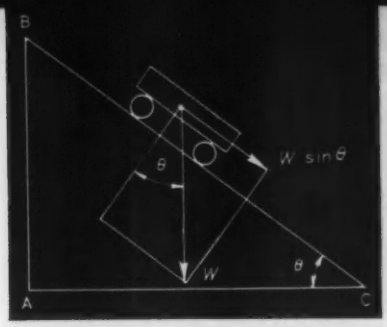


Fig. 6 Rolling resistance of a wagon

fences are often helpful. Welded rails, too, eliminate resistance due to impact at rail joints, although welding is not possible throughout the track-circuited area of the switching zone. In the USA, the injection of hot oil into axle-boxes prior to humping has been claimed to be helpful in reducing inconsistency, but the opinion of British and Continental railway engineers is that the mass of the axle box and the oil already in it is such that the injected oil cools too rapidly to be of much assistance.

In these circumstances, designers of marshalling yards use average figures obtained from the results of tests which include track resistances. A rolling resistance coefficient of 0·004 is considered to be typical for a good running wagon and a figure of 0·008 for a poor running wagon (*1*).

Hump radius depends on wagon length

Before the gradients in the yard can be determined, it is necessary to settle the vertical curve over the hump, since the accelerating point depends on its radius (*2*).

In Fig. 7, at the instant of acceleration, the coefficient of wagon rolling resistance μ is $\sin\theta = \theta$ for small angles.

Also $L = R\theta$.

But as μ varies from μ_{max} to μ_{min} according to wagon resistance,

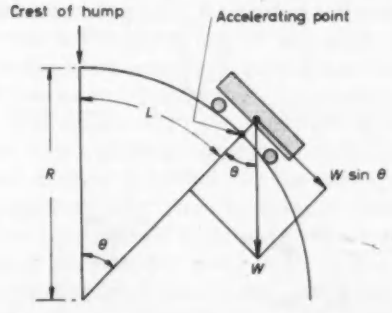
$$\begin{aligned} &L_{max} - L_{min} \\ &= R(\theta_{max} - \theta_{min}) \\ &= R(\mu_{max} - \mu_{min}) \end{aligned}$$

When $L_{max} - L_{min} \leqslant$ wagon length, in the worst case two wagons will not separate. The maximum radius for the vertical curve is therefore

$$R = \frac{\text{Wagon length}}{\mu_{max} - \mu_{min}} \qquad \ldots (5)$$

(The radius of the vertical curve must be less than R to ensure adequate separation.)

Fig. 7 The vertical curve over the hump



Assuming $\mu_{max} = 0{\cdot}02$ and $\mu_{min} = 0{\cdot}004$, and taking the shortest length of a British wagon as 20 ft, the maximum permissible radius is found to be 1250 ft. The minimum radius is that which can be safely negotiated by locomotives passing over the hump. A typical figure for the radius is 660 ft.

Determining the gradients

The gradients in the switching zone and marshalling sidings may now be determined. In order that wagons may accelerate rapidly and thus achieve the greatest possible separation between cuts before arriving at the primary retarders, one must provide as steep an initial gradient as practicable. Typical gradients are 1 in 18 (5·5%) and 1 in 20 (5%), but the gradient must be eased approaching the primary retarders, which ultimately ensure good separation between the cuts. The retarders must, however, be on an accelerating gradient so that in the event of a cut being stopped inadvertently in the retarders, it will roll out when released. A suitable gradient through the primary retarders is 1 in 50 (2%), but for the secondary retarders a gradient of 1 in 80 (1·25%) will suffice. The gradient in the marshalling sidings should be non-accelerating for the good running wagon and 1 in 250 (0·4%) is typical.

A graphical construction, due to Kubale(*1*), may be used to determine the final gradients and time-distance curves for wagons with varying rolling resistances following one another over the hump.

The construction is very simple. It is based on equation 3 ($H = Kv^2$). Consideration will show that if

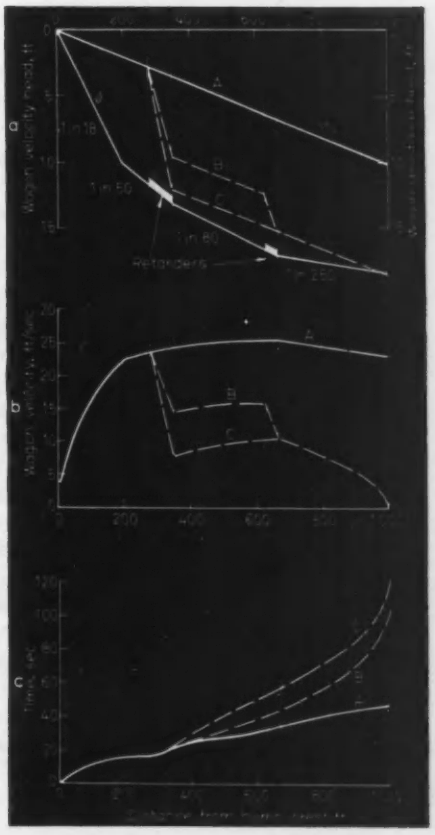


Fig. 8 Typical example of graphical calculation of velocity-time and distance-time curves for wagons passing through switching zone

the gradient profile is plotted as shown in Fig. 8a, the vertical height to the datum line represents H, now to be known as the ' velocity head '. If lines are also drawn representing various values of combined wagon and track resistance and the value of H taken as the vertical distance between that line and the hump profile line below, the speed of the wagon at that point may be calculated by rewriting equation 3 as

$$v = \sqrt{\frac{H}{K}}$$

This will give the speed of the wagon at the point corresponding to the value of H.

This results in the speed-distance curve of Fig. 8b, which may be integrated graphically to give the time-distance curve of Fig. 8c.

In calculating the speed it is necessary to add to H the velocity head corresponding to the humping speed, and the wagon resistance lines must each begin at the corresponding accelerating point on the vertical curve. It is easy to see from these diagrams how wagons having different resistances will move in relation to one another. The braking effect of the retarders may also be shown by assuming that the wagon has greatly increased rolling resistance during retardation.

Fig. 8 shows, in full line, an unretarded wagon A, having a total rolling resistance coefficient (i.e. wagon, track and air resistance) of 0·001. It shows the same wagon retarded by primary and secondary retarders B to bring it to a standstill 1000 ft from the crest of the hump and again C by the primary retarder alone.

It is usual, in making calculations, to assume a higher humping speed than is used in practice and for the purposes of Fig. 8 it has been taken as 4 ft/sec.

Types of retarder and their construction

A wagon retarder (Fig. 9) consists essentially of longitudinal braking shoes mounted in pairs, one each side of each running rail. In the normal position the wagon wheels are free to pass unrestricted, but in the retarding position the braking shoes are forced against the rim of the wheels, about 4 in. above rail level.

There are two categories of retarder namely the *weight-automatic* and the *non-weight-automatic*. The principle of operation of the weight-automatic retarder is shown in Fig. 10a. The inner braking rail is so designed that in the retarding position the wagon runs on the wheel flanges through which the weight of the wagon causes the retarder to close and apply a braking force proportional to the weight. It is usual for the retarder to be operated to the braking position prior to the entry of the wagon and in these circumstances comparatively little power is required. But on occasions it is necessary for the retarder to operate during the passage of a wagon. This means that the wagon must, in effect, be lifted to retard it and then much greater power is required. For this reason, the weight-automatic retarder is operated hydraulically.

Fig. 10b shows the principle of operation of the non-weight-automatic retarder. These retarders are generally

Fig. 9 A typical retarder, showing the long braking shoes on each side of the rails and the radar aerials in the centre of the track at the hump end

electropneumatically operated and the retarding force is proportional to the pressure applied.

Primary retarders are generally 72 ft long and secondary retarders are 36 or 48 ft long, the speed of the wagons approaching the secondary retarders being much lower. The energy to be absorbed by a retarder is equal to the difference between the kinetic energy of the vehicle or vehicles entering the retarder and the kinetic energy on leaving the retarder. In emergency, a wagon may have to be stopped by the retarder, and its energy absorption capacity must be sufficient for this.

Assuming that a loaded 22-ton 2-axle wagon (tare weight 10·35 tons) is travelling at a speed of 25 ft/sec, the kinetic energy to be absorbed by a primary retarder if the wagon is to be stopped is 724,460 ft-lb. The energy absorption capacity of the retarder must therefore be not less than 5574 ft-lb/ft/axle, assuming the effective length of the primary retarder to be 65 ft. This is well within the capacity of a modern retarder but the example gives some idea of the energy involved.

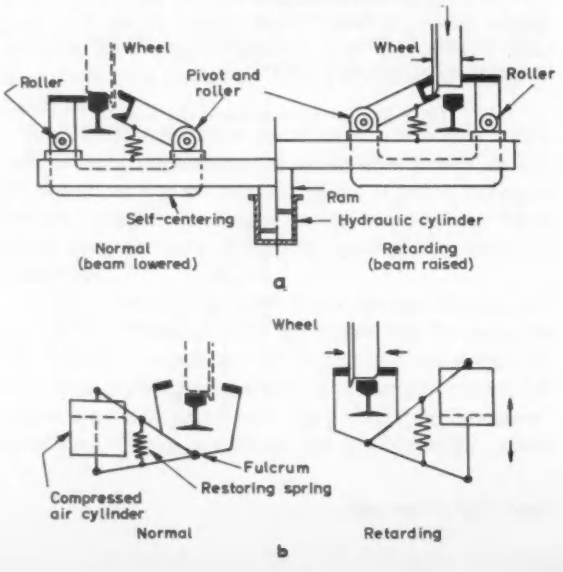
At the secondary retarder, the speed will be very much less than at the primary retarder since the former is provided only to correct the retardation applied at the latter.

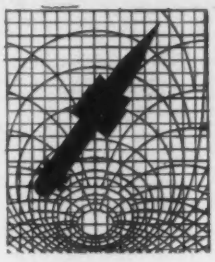
To be concluded

Reference

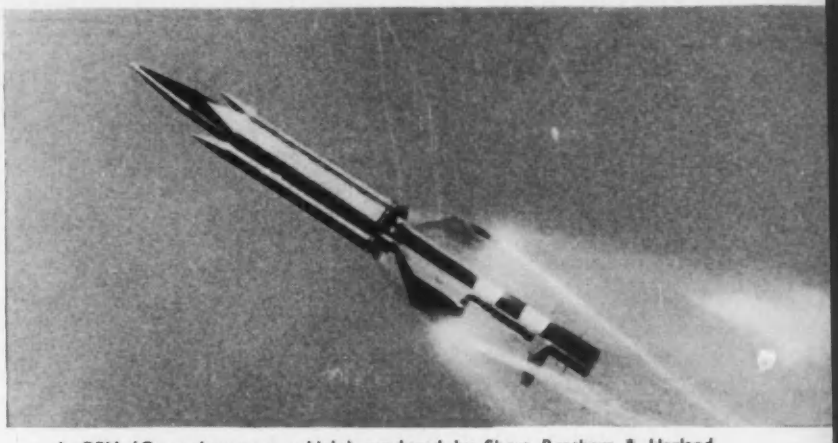
1. Webb, D. C.: ' Automatic Operating in Marshalling Yards,' *Proc. Instn. Rly. Signal Engnrs.*, 1957, *p.* 55.

Fig. 10 Principles of retarder mechanisms
a Weight-automatic retarder, hydraulically operated
b Non-weight-automatic retarder, electropneumatically operated





Proportional navigation is used with the semi-active homing missile whose theory is outlined here



A GPV (General-purpose vehicle) produced by Short Brothers & Harland, employing the Badger semi-active homing head designed by Elliott Brothers

Semi-active homing

by **J. L. SENDLES,**
formerly of Elliott Brothers, and now with Short Brothers & Harland

IN THIS ARTICLE I SHALL DESCRIBE A BASIC CONTROL and guidance system for a typical semi-active homing missile, employing a *proportional navigation* system, which attempts to make the rate of turn of the missile's flight path proportional to that of the line joining the missile and target. I shall assume that the missile has a cruciform wing and fin configuration with rear control surfaces, and that it is accelerated to supersonic speeds by a set of wrap-around booster motors which are jettisoned at burnout. Also, the missile is assumed to be roll position stabilized throughout the homing phase of the flight.

Autopilot modifies aerodynamic response

The lateral aerodynamic response of the uncontrolled missile, that is the lateral rate of turn of the missile's body, or the lateral acceleration resulting from a step displacement on an opposite pair of control fins, is too sluggish and underdamped for a practical system. Furthermore it is completely dependent upon the height and speed of the missile and therefore varies considerably throughout flight. Thus the designer must modify the natural aerodynamic response of the missile by the inclusion of an autopilot, which feeds back characteristics of the missile's motion to the control fins.

The autopilot in the missile considered here feeds back the missile's pitch and yaw lateral rates of turn, as measured by two rate gyroscopes, to the respective pitch and yaw control fins. Although this type of autopilot only slightly increases the speed of response, the damping can be optimized by adjustment of the rate of feedback gain, to suit most requirements for low altitude investigations.

Increase of damping factor

Fig. 1 shows a block diagram of the yaw lateral control loop. A similar loop exists for the pitch plane of the missile. The relations between the fin demand ζ_D, the fin angle ζ, and the resulting rate of turn r, of the missile's body can be seen from Fig. 1 (using the Laplace notation) to be

$$\zeta = K_g(\zeta_D + \beta r) \qquad \ldots (1)$$

[It is assumed that $Y_g(S) = 1$ and $Y_g(S) = 1$ since ω_g and $\omega_g \gg \omega_0$]

and $$\frac{r}{\zeta} = -\frac{K_0(1 + T_I S)\omega_0^2}{S^2 + 2u_0\omega_0 S + \omega_0^2} \qquad \ldots (2)$$

where T_I is the incidence time-constant.

Equations 1 and 2 give

$$\frac{\gamma}{\zeta_D} = -\frac{K_M(1+T_1 s)\omega_M^2}{s^2 + 2u_M\omega_M s + \omega_M^2} \qquad \ldots (3)$$

where

$$K_M = \frac{K_B K_O}{1 + K_B K_O \beta} \qquad \omega_M = \omega_O\sqrt{(1 + K_B K_O \beta)}$$

and $$u_M = \frac{2u_O + K_B K_O \beta T_1 \omega_O}{2\sqrt{(1 + K_B K_O \beta)}}$$

It can be seen that the transfer function between r and ζ_D (equation 3) is analogous to that between r and ζ (equation 2) with K_O, ω_O and u_O replaced by K_M and ω_M and u_M as given above. The most significant effect of the rate feedback autopilot is to increase the damping factor from u_O to u_M, although the natural frequency has also been modified from ω_O to ω_M.

The relation between the missile's flight path rate $\dot{\psi}_F$ and the corresponding body rate r (see Fig. 2) is

$$\frac{\dot{\psi}_F}{r} = \frac{1 - T_1 T_F s(s - n_r)}{1 + T_1 s} \qquad \ldots (4)$$

where T_F is the fin lift time-constant and n_r is an aerodynamic derivative. Thus the relation between the missile's flight path rate ψ_F resulting from a fin demand ζ_D is, from equations 3 and 4,

$$\dot{\psi}_F = \frac{-K_M[1 - T_1 T_F s(s - n)]\omega_M^2 \xi_D}{s^2 + 2u_M\omega_M s + \omega_M^2} \qquad \ldots (5)$$

Rolling the missile

The roll control of the missile has two distinct modes of operation, the first being operative during the boost

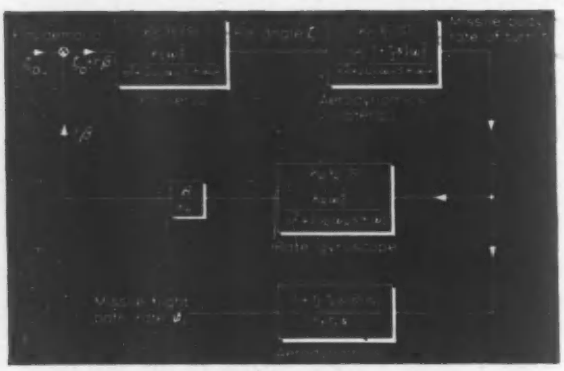


Fig. 1 Block diagram of the yaw lateral control system

phase and the second taking over when the boost motors have been jettisoned at burnout.

In order that the missile remains on a reasonably even trajectory during the boost phase, that is, while the speed is being built up, the missile is rolled. This is achieved by purposely offsetting the boost motors so as to produce a roll torque, but owing to a guidance requirement the roll rate thus developed must be limited. A roll rate limiting system therefore operates during the boost phase. Also, in order to simplify the analysis of the telemetry records of the missile's performance during the homing phase of the flight, the missile is roll position stabilized to a horizontal datum supplied by a roll position gyroscope.

During the boost phase the roll rate is limited, whenever it exceeds a threshold value, by offsetting the four control fins in roll with a signal proportional to the roll rate. This roll rate signal is produced within a roll computer by differentiating the output of the roll position gyroscope. Throughout the roll rate limiting phase the roll position output of the computer, which is required for roll position stabilization, is disconnected from the control fins, and the roll rate output, which has a high gain (K_B) compared with those (K_C and K_C') required for roll position stabilization is connected. This switching operation is carried out by the relay in Fig. 3, which is a block diagram of the complete roll control system.

Equations of roll motion

Assuming the roll rate due to the boost torque alone is $\dot{\phi}_B$, the equations of roll motion during the boost phase can be seen, from Fig. 3, to be

$$\xi \cdot \frac{K_A}{1 + T_A s} = \dot{\phi} - \dot{\phi}_B \qquad \ldots (6)$$

Also

$$\xi = -\frac{(\dot{\phi} - \dot{\phi}_T)K_{RG}K_B K_S}{(1 + T_{RC}s)} \quad \text{when } \dot{\phi} > \dot{\phi}_T \qquad \ldots (7)$$

$$= 0 \qquad \text{when } \dot{\phi} < \dot{\phi}_T$$

where $\dot{\phi}_T$ is the threshold roll rate.

Assuming $\dot{\phi} > \dot{\phi}_T$, we have from equations 6 and 7

$$\dot{\phi}_B - \dot{\phi} = \frac{(\dot{\phi} - \dot{\phi}_T)K_A K_{RG} K_B K_S}{(1 + T_A s)(1 + T_{RC}s)} \qquad \ldots (8)$$

Now since $\dot{\phi}_B$ changes sufficiently slowly, derivatives of $\dot{\phi}$ greater than the first can be neglected. Equation 8 thus becomes

$$\dot{\phi}_B - \dot{\phi} = (\dot{\phi} - \dot{\phi}_T)K' \qquad \ldots (9)$$

where $K' = K_A K_{RC} K_B K_S$

so that if the roll rate, due to the boost torque, in excess of the threshold value, is $\triangle$, then from equation 9

$$\dot{\phi} = \dot{\phi}_T + \frac{\triangle}{1 + K'} \qquad \ldots (10)$$

We can see from equation 10 that in order to minimize the excess of the roll rate over the threshold value, the rate gain K_B of the roll computer during the boost phase, and therefore K' must be increased as far as practical limits allow.

Obtaining roll position stabilization

Roll position stabilization operates only within a small zone about the datum supplied by the roll position gyroscope. Outside this region the system becomes a roll rate system. This arrangement ensures that if roll position stabilization is switched in when the missile is at a large angle off the roll datum the missile will not

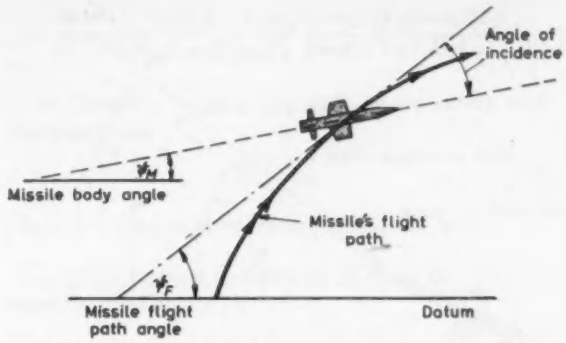


Fig. 2 How the missile's flight path angle of yaw is defined

accelerate to large roll rates but will roll in towards the datum at a controlled rate. On reaching the inner zone roll position stabilization takes over and the missile stabilizes onto the roll datum.

In order to achieve roll rate stabilization within the outer zone, the roll position output of the roll computer is limited to $\pm\phi_L$ (these being the limits over which roll position stabilization operates), and the roll rate gain of the computer becomes K_C.

Referring again to Fig. 3, we can see that the equation of motion in the outer zone is

$$\phi = \frac{K_A\xi}{s(1 + T_A s)} \qquad \ldots (11)$$

where

$$-\xi = \frac{K_{RG}K_C K_S}{(1 + T_{RC}s)}s\phi \pm K_{RG}K_S\phi_L \qquad \ldots (12)$$

On eliminating ξ from equations 11 and 12 we have

$$\left(s^2 + \frac{T_A + T_{RC}}{T_A T_{RC}}s + \frac{K_{RG}K_C K_S K_A + 1}{T_A T_{RC}}\right)\dot{\phi}$$

$$= \pm \frac{K_{RG}K_C K_S K_A \phi_L}{T_A T_{RC}(1 + K_{RG}K_C K_S K_A)} \qquad \ldots (13)$$

whose steady state solution is

$$\dot{\phi}_{SS} = \pm \frac{K_{RG}K_C K_S K_A}{(1 + K_{RG}K_C K_S K_A)^2}\phi_L$$

The mode is stable with natural frequency ω_1 and damping factor u_1, given by

$$\omega_1^2 = \frac{K_{RG}K_C K_S K_A}{T_A T_{RC}} + 1$$

and

$$2u_1\omega_1 = \frac{T_A + T_{RC}}{T_A T_{RC}}$$

Hence the steady state roll rate achieved by the missile when rolling into the datum from a large angle may be set to the required value by adjustment of ϕ_L.

As the missile rolls into the inner zone of roll position stabilization the limits are removed from the roll position output of the computer and the roll rate gain becomes K_C'.

Thus the equations for motion in the inner zone become

$$\phi = \frac{K_A}{s(1 + T_A s)}\xi \qquad \ldots (14)$$

where

$$\xi = -K\phi - \frac{K_{RG}K_C' K_S s}{(1 + T_{RC}s)}\phi \qquad \ldots (15)$$

Equations (14) and (15) give

$$\left(s^3 + \frac{T_A + T_{RC}}{T_A T_{RC}}s^2 + \frac{1 + K_A K T_{RC} + K_A K_{RG}K_C' K_S}{T_A T_{RC}}s + \frac{KK_A}{T_A T_{RC}}\right)\phi = 0 \qquad \ldots (16)$$

The characteristic equation above with the correct choice of the parameters represents a stable mode; the values of K and K_C' are adjusted to give an optimum response for all initial conditions of the roll rate as the missile enters the zone of roll position stabilization.

Proportional navigation

In order to guide a homing missile by proportional navigation one must measure the rate of turn of the line joining the missile and the target (sight line) and use this information in order to attempt to make the

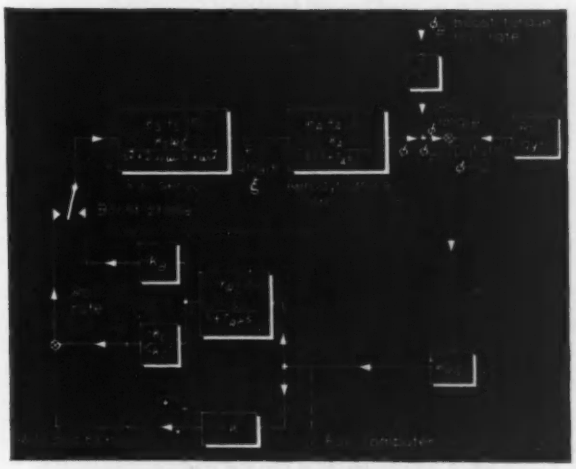


Fig. 3 Block diagram of the roll control system

missile's flight path turn at a proportional rate. The object of the homing head situated in the front of the missile is to measure the rate of turn of the sight line. This information is then fed back to the control fins in order to manoeuvre the missile so that its flight path has the required rate of turn.

How the homing head operates

I next describe the functioning of the homing head. The target is illuminated by a radar beam emitted from a ground-based radar transmitter or 'lamp set' which automatically follows the target. Radar waves reflected by the target are received by an aerial situated in a

reflector or dish on the front of the homing head, and their frequency is converted to an intermediate frequency by mixing them with the output of a local oscillator. The incoming radar signal is amplitude modulated by the aerial performing a conical scan about the dish axis, with the depth of modulation proportional to the angular error between the dish axis and the sight line. This signal is phase sensitive detected and resolved in order to give the angular errors in elevation and azimuth between the dish axis and the sight line. These errors are now used to precess a free gyroscope (line-of-sight-gyroscope), onto which the dish is slaved by two follow-up electrohydraulic servos so as to reduce the radar errors to zero and hence keep the dish aerial system looking at the target. This loop is known as the auto-follow or tracking loop and operates in both the yaw and pitch planes of the missile. A block diagram of the yaw tracking loop is given in Fig. 4, with the associated symbols illustrated in Fig. 5. It can be seen from the block diagram that

$$(\psi_S - \psi_D)K_R K_G Y_R Y_G = \psi_G \qquad \ldots (17)$$

and

$$(\psi_G - \psi_D)\, K_D Y_D = \psi_D - \psi_M \qquad \ldots (18)$$

On eliminating ψ_D, we obtain

$$\psi_G = \left(\psi_S - \frac{\psi_M}{1+K_D Y_D}\right)\left(\frac{K_R K_G Y_R Y_G}{1+K_R K_G Y_R Y_G \dfrac{K_D Y_D}{1+K_D Y_D}}\right) \qquad \ldots (19)$$

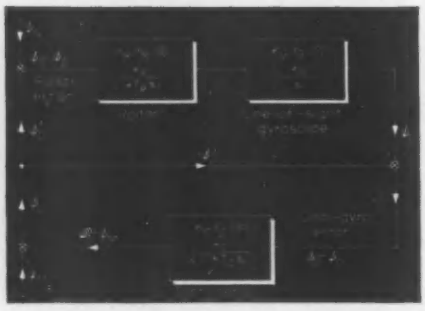


Fig. 4 Block diagram of the yaw tracking system

Now supposing there is no missile body motion, that is $\psi_M = 0$, equation 19 becomes

$$\psi_G = \frac{K_R K_G Y_R Y_G}{1+K_R K_G Y_R Y_G \dfrac{K_D Y_D}{1+K_D Y_D}}\, \psi_S$$

Therefore, assuming the dish servo stiffness K_D is large, and by differentiating with respect to time, we have

$$\dot{\psi}_G = \frac{K_R K_G / T_R}{s^2 + s/T_R + K_R K_G / T_R}\, \dot{\psi}_S \qquad \ldots (20)$$

Hence the line-of-sight gyro precession rate lags the sight line rates with a quadratic lag, whose natural

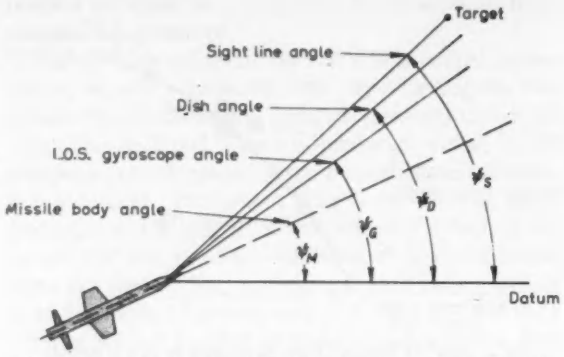


Fig. 5 Showing the meaning of the symbols associated with the yaw tracking loop

frequency and damping factor may be optimized by the adjustment of the radar gain K_R and the radar time-constant T_R.

Dish-missile coupling

In the presence of missile body motion and no sight line motion, equation 19 becomes, on differentiating,

$$\dot{\psi}_G = -\frac{K_R K_G / T_R s(1+sT_D)}{(s^2 + s/T_R + K_R K_G / T_R)K_D}\, \dot{\psi}_M \qquad \ldots (21)$$

which at low frequencies reduces to

$$\dot{\psi}_G = -\frac{s\dot{\psi}_M}{K_D} \qquad \ldots (22)$$

This coupling of the missile body motion into the line-of-sight-gyro motion is known as *dish-missile coupling*, and as equations 21 and 22 illustrate, it is due to the finite stiffness K_D of the dish servo.

Since dish-missile coupling has a de-stabilizing effect on the system when the missile's guidance loop is closed, the dish servo stiffness K_D must be made as large as possible, or if this is not sufficient to reduce the coupling below the level required for a reasonable missile performance, devices may be introduced into the system in order to eliminate this type of coupling.

Proportional navigation as already stated is achieved by making the missile's flight path rate proportional to the sight line rate, but as equation 24, relating ψ_S and ψ_F, shows, this is only true for the steady state condition.

Assuming that there is no dish missile coupling, equation 20 holds. Also from the block diagram of the yaw tracking and guidance loops (Fig. 6) we can see that

$$\frac{\dot{\psi}_F}{\dot{\psi}_G} = \frac{k\omega_A^2[1+sT_1T_F(s-n_r)]}{(s^2+2u_A\omega_A s+\omega_A^2)(1+T_N s)(1+T_L s)} \qquad \ldots (23)$$

Thus from equations 20 and 23

$$\dot{\psi}_F = \frac{k(K_R K_G/T_R)\omega_A^2[1+sT_I T_F(s-n_T)]\psi_B}{(s^2+2u_A\omega_A s+\omega_A^2)(1+T_N s)(s^2+s/T_R+K_R K_G/T_R)(1+T_I s)} \quad \ldots (24)$$

It can therefore be seen that only in the steady state condition does

$$\dot{\psi}_F = k\dot{\psi}_B \quad \ldots (25)$$

where k is the yaw proportional navigation factor.

A similar relation to equation 24 holds for the pitch flight path and line of sight rates.

Radome aberration

Mounted on the front of the missile is a radar transparent radome which encloses the dish aerial combination of the homing head. The radar waves reflected from the target are refracted on passing through the radome. This results in the dish aerial combination detecting radar errors between the dish axis and an apparent sight line instead of the true sight line as in the case without a radome. The effect of this radome aberration is to modify the proportional navigational constant and to introduce a coupling between the sight line and the missile's body motion. This may be seen by assuming that the angle between the true sight line and the apparent sight line is a function of the angle

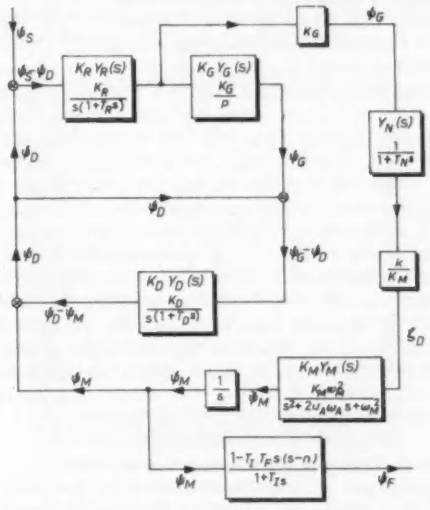


Fig. 6 Block diagram of the complete guidance and control system in yaw

of incidence that the true sight line makes with the surface of the radome (see Fig. 7).

$$\varepsilon = f(\psi_B - \psi_M)$$

or

$$\varepsilon = A(\dot{\psi}_B - \dot{\psi}_M) \quad \ldots (26)$$

Where A (the aberration slope) $= \dfrac{\partial\varepsilon}{\partial(\dot{\psi}_B - \dot{\psi}_M)}$

Now

$$\psi_{BA} = \psi_B + \varepsilon$$

Therefore

$$\psi_{BA} = \psi_B + \varepsilon \quad \ldots (27)$$

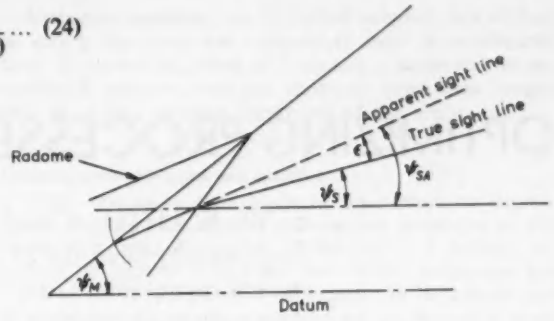


Fig. 7 Aberration caused by the radome

where the rate of change of the sight line angle as detected by the homing head in the presence of a radome is $\dot{\psi}_{BA}$, which, from equations 26 and 27, can be seen to be equal to

$$\dot{\psi}_{BA} = \dot{\psi}_B(1 + A) - A\dot{\psi}_M \quad \ldots (28)$$

The relation between the missile's flight path rate and the true sight line rate may be obtained by substituting $\dot{\psi}_{BA}$ from equation 28 for ψ_B in equation 24, which gives in the steady state condition

$$\psi_F = \frac{k(1 + A)}{1 + kA}\ \psi_B \quad \ldots (29)$$

Thus from equation 29 it can be seen that in the presence of radome aberration of slope A the proportional navigation factor k becomes $k(1 + A)/(1+kA)$. Furthermore the system is exponentially unstable whenever $1 + kA \leqslant 0$.

Conclusion

Recapitulating, we have seen that the missile is rolled during the boost phase in order to reduce dispersion and that owing to a guidance requirement the roll rate is limited. Also, in order to simplify the analysis of the homing flight, the missile is roll position stabilized to a datum supplied by a roll position gyroscope.

Since the natural aerodynamic damping of the missile is too low, feedback from lateral rate gyros to the respective control fins is applied in order to increase the overall damping of the lateral aerodynamic loops. This type of autopilot also slightly increases the speed of response.

Proportional navigation is achieved by offsetting the control fins with a signal proportional to the sight line rate, which is measured by the homing head, so as to turn the missile's flight path at a proportional rate. We have seen that this is only true in the steady state conditions owing to the inherent lags in the system. Two destabilizing effects on the guidance of the missile have been mentioned, namely, dish-missile coupling, due to the finite stiffness of the dish servos, and the aberration of the sight line produced by the radome.

OPTIMIZING PROCESSES AND THEIR CONTROL

E. W. R. LITTLE, Chief Instrument Engineer of the Engineering Division of the Distillers Co., reports a recent symposium on the use of instruments and computers in process plant design and control—a symposium which was coloured by a masterly and stimulating address from Sir Harold Hartley

LAST MONTH THREE MEMBER SOCIETIES OF THE BRITISH Conference on Automation and Computation organized jointly a three day symposium on Instrumentation and Computation in Process Development and Plant Design, which was held in London at the Central Hall, Westminster. These societies were the Institution of Chemical Engineers, the Society of Instrument Technology and the British Computer Society, and their symposium brought together some 500 chemical engineers, instrument and control engineers and computer specialists; a good feature of the attendance was that there were about 25 visitors from abroad.

As was so aptly stated by Sir Harold Hartley in his inspiring closing address to the assembly on 'The Future', 'With the increasing complexity of every operation the material welfare of mankind in the years that lie ahead

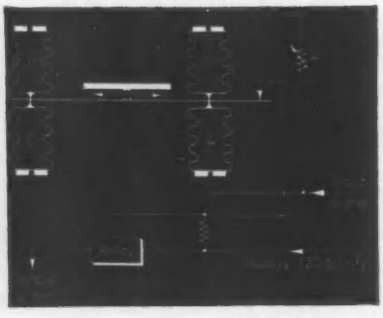


Fig. 1 A frequency selective attenuator (Samson)

will depend more and more on the combined operations of specialists—provided, of course, that they are engaged in peaceful tasks'. He reminded his audience that the common objective running through all the papers was production by the most economical means, an obvious goal if we are ever to meet the needs of the world's growing population, with its demand for higher standards.

Great interest in control developments

It was perhaps no surprise that, in spite of a majority of chemical engineers among those present, the greatest interest, as evinced by a lively discussion, centred round developments in control engineering.

Two analogue computing devices

Redding, of Evershed & Vignoles, described a simple electrical computing device, capable of addition and multiplication and, because of its analogue mechanism, suitable for insertion in control loops. As this device deals only with algebraic equations it can be used only in computing the steady state of the plant, such as the correction of measurements to standard conditions, the calculation or simulation of a parameter which cannot be measured directly, or the provision of a signal representing a derived quantity such as a ratio. It is thus complementary to the conventional controller, which, as is well known, acts as an analogue computer solving a differential equation in real time. Algebraic analogue computers have a wide potential application in the correction of external disturbances to a process by means of feed forward, based on a measure of the disturbing condition.

Samson, until recently with Foxboro-Yoxall, described another type of simple analogue computing device used to provide a special control action to suit an atypical process application. His paper provides a practical illustration of the way in which, once the transfer functions of a process are known, they can be electrically simulated. Control theory having indicated a suitable transfer function to complete a stable closed loop, the values of the components were found experimentally on the analogue.

Fig. 1 illustrates the principle of the pneumatic device designed, as a result of the investigation, to interpose between a proportional controller and a control valve.

Problems in the control of steel sheet rolling mills were discussed in separate papers by Jenkins, of BISRA, and Kopai-Gora, of the Institute for Scientific Research in Computing Machinery, Moscow, which are illustrative of the earlier stages of similar but more complicated investigations.

Statistical methods—for fluctuating and steady states

Determination of transfer functions by statistical analysis of the effects of randomly fluctuating inputs to a plant under normal running conditions was dealt with in a paper by Florentin, of the Imperial College of Science and Technology, and three collaborators. Such an unpromising technique would be attempted only where the plant was not available for the injection of test signals or when the presence of a large amount of noise in the plant made difficult the measurement of response to test signals.

By way of contrast the paper by Coutie, of ICI (Dyestuffs), showed with commendable clarity the effectiveness of a statistical analysis when applied to steady-state equilibrium. Because of the great complexity of many modern chemical processes, methods for improving efficiencies often have to be entirely empirical. Statistical methods are used to separate real effects from inherent errors that are always present.

The method is to make systematic small modifications

in the operating conditions of a running plant, following a carefully planned and continuously repeated cycle. Because the modifications are small their effect is probably not detectable until the results of several successive cycles are averaged.

Instrument accuracy is the limiting factor

As pointed out in discussion by Himsworth, of ICI (Billingham), such techniques make severe demands on both the accuracy of measuring instruments and their stability over long periods of time, so that the application of statistical analysis in control engineering is more likely to be limited by the relatively low accuracy of instruments currently available than by any other single factor. Moreover such investigations, being usually concerned with quality of product, give renewed urgency to the current search for quality measuring instruments.

I may mention here that the dynamics of a process are necessarily involved when an attempt is made to control at the desired steady state, and any delay in the response of measuring instruments to process variables is deleterious to the overall performance of the plant.

Optimization

The aim of all steady-state investigations is optimization either to a maximum—as of yield or throughput per unit time—or to a minimum—as of the cost of energy and material inputs for given product quality or quantity. Although many factors may influence the course of the process, investigating two or three parameters at a time makes for easy visual interpretation of the results.

In the example illustrated in Fig. 2 the effect on the cost of product of the temperature of reaction and initial concentration of one of the reactants is shown in the form of response contours. A peak represents a unique solution

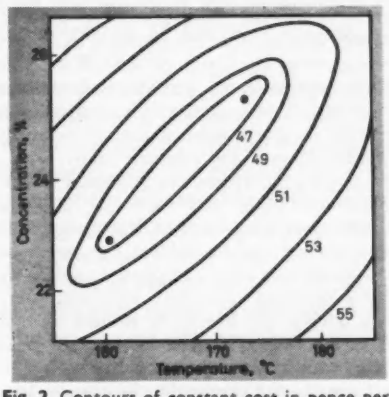


Fig. 2 Contours of constant cost in pence per pound weight (Coutie)

but ridge systems such as the one shown are more frequent: the required solution then depends on some secondary characteristic (purity in this example).

It is of great practical importance to determine the optimum as efficiently as possible. Witenberg, of the Institute for Scientific Research in Computing Machinery, Moscow, outlined three possible techniques, agreeing with Coutie that the maximum gradient method is best. But in discussion Rosenbrock, of Constructors John Brown, claimed that the maximum gradient vector was liable to oscillations of direction and that the total progress vector, being more stable, was preferable.

Digital computers have efficient memory devices and high accuracy but are complicated in construction and slow acting (owing to the iterative methods required). Hence they are very difficult to operate in real time.

Analogue computers are of limited accuracy but so fast in action that they are customarily used in accelerated time. Moreover the effect of changing a parameter is immediately apparent and the analogue often aids insight into the actual physical behaviour of the system.

Choosing between digital and analogue

Many references were made to the correct choice between the two, the diverse applications presented to the conference being illustrative of the nicety of decision required; in general it is clear that digital computers are more suited to the solution of steady-state equations and analogue computers more appropriate for the solution of differential equations and the study of process stability.

The process of choice was skilfully illustrated by Sage, of ICI (Plastics). For a device required to match shaft speeds digital measurement was chosen as being accurate and insensitive to external influences, employing a simple and robust transducer; moreover differences are readily computed. One disadvantage of the digital method is the sampled nature of the error signal. This has been overcome by cascading the digital control loop through a conventional analogue speed control. In his paper Sage brings out the incidental advantage in such a procedure of an ability to use a highly reliable analogue system alone, while remedying any failures in the more complex digital system ('ability to grade failures').

Discussion emphasized that anything which complicates a measuring transducer is deleterious to the system reliability. In order to keep down cost the number of specially designed components in a system should be kept to a minimum.

A flow controller for in-line blending, designed by Idzerda of the Koninklijke/Shell Laboratorium, Amsterdam, adopts an ingenious analogue device as a solution to a very similar counting problem, and though justified on grounds of its simplicity, and hence cheapness, some doubt existed at the symposium whether the departure from the principles outlined above was altogether sound.

Ambitious and thought-provoking

The most thought-provoking paper was presented by Shapiro, of the IBM Research Laboratory, New York, on behalf of his co-authors Kalman and Lapidus, also from the USA. It was a most ambitious theoretical attempt to bring together the previous lines of thought and to outline a possible automatic process optimization system, capable of adjusting not only the steady-state process conditions but also the control networks required for optimum operating stability.

Presentation was marred by an attempt to show that all could be done by a digital computer and by giving too great a prominence to the details of the mathematics—although it is conceded that mathematical development is the first stage of actual design: control engineers would be well advised to digest the equations at their leisure.

The authors draw attention in their paper to the recent work by Eckman and Lefkowitz*(1)*, which shows clearly that for a batch process with empirically determined kinetics the use of computer control can provide a yield path for the product superior to that which can be achieved under human control.

The control engineer may conclude that his future will surely embrace computer-controlled plants. These will probably always be the exception rather than the rule, because the economic advantages to be gained must be set off against the not inconsiderable capital charges arising from investment in the computer.

Such a computer will possibly contain a digital pro-

gramming and data-reduction section, enabling optimum control to be established with respect to the equilibrium values of a multiplicity of process variables. Shapiro, Kalman and Lapidus visualize an 'optimal hyperplane' for the process in place of Coutie's more limited 'peak' or 'ridge'. This optimum will be continuously and automatically adjusted to take account of external conditions (such as the feedstock or the market price) and internal changes (such as catalyst activity).

The programming section is visualized as introducing transient test signals to determine the dynamics of the process, leading to the establishment of its analogue and thence to an optimum arrangement of control loops. Bearing in mind the need for speed and reliability it is hard to see that these loops could ever be other than analogue in nature. In his closing address, Sir Harold Hartley said on this point, 'Professor Gabor, in his recent inaugural lecture, gave a preview of his predictor which is an analogue computer for carrying out the dynamic control of a process in the optimal way. It is capable of adjustment according to the process which it is controlling . . . . This shows one way in which our present analogue controllers may develop—by becoming more general and by having facilities by which a digital computer can set them to the best response'.

Characteristics of a distillation column

Keating and Townend, of British Petroleum, have used a digital computer to study the steady-state relationships between independent variables and product quality in a distillation column. This throws some light on the criteria which aid in the selection of control loops but is ineffective compared with study of the dynamic characteristics of the column, now to be undertaken.

Such a study has been carried out on an analogue computer by Rijknsdorp and Maarleveld, of the Koninklijke/Shell Laboratorium, Amsterdam (Fig. 3). As the authors say, most published studies in this field assume pressure and tray hold-up to be constant. As a result the results mainly give the low frequency part of the dynamics, useful in describing responses to variations in feed composition and in

courtesy Koninklijke/Shell Laboratories, Amsterdam

Fig. 3 The analogue computer used for study of distillation columns by Rijnsdorp and Maarleveld

finding the approach towards equilibrium during start-up.

On the other hand the high frequency part of the dynamics is important for the study of column control, because the resonance zones of pressure and temperature control are often in this region. It is obvious that pressure control can be analysed only if the assumption of constant pressure is dropped.

The authors are to be congratulated on devising an analogue largely consisting of passive networks, as shown

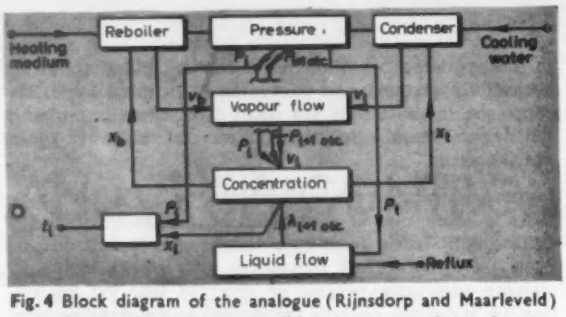


Fig. 4 Block diagram of the analogue (Rijnsdorp and Maarleveld)

All variations in column conditions are expressed as voltages, designated by the following symbols:

t = temperature	X = concentration of component in the liquid
P = pressure	λ = fictitious liquid flow variation
V = vapour flow	

Subscripts refer to the column position:

b = bottom	i+1 = tray above No. i
i = tray No. i	t = top

in Fig. 4. This is at once more reliable and less expensive than the usual analogue with its multiplicity of amplifiers.

Control engineers must work with plant designers

According to Lunt, of ICI Central Instrument Laboratories, an analogue machine suitable for a large proportion of the problems likely to be met in the chemical industry would require a capacity of about 200 amplifiers. Another point made by the same author was that the activities of the control engineer should be organized within the works department which is responsible for the investigation of processes and the improvement of technical efficiencies, for if the best use is to be made of controls the plant itself must be designed so as to have suitable response characteristics. He can with advantage divorce himself from the actual maintenance organization but must still be fully aware of the need for designs which lend themselves to easy maintenance procedures.

Two papers dealing with the problem of economic plant design were noteworthy. Lyon, of the UKAEA, took as an example the separation of deuterium, and showed how, with the aid of a digital computer, curves could be plotted relating choice of steady-state operating conditions to the sum of capital charges and running costs.

A novel and highly instructive approach to the problem of economic estimation was made by Gillings, of ICI Central Instrument Laboratory. Rightly appreciating the approximate nature of the subject, he has used a small specially designed analogue computer to take into account varying rates of plant operation, variations of costs and realizations during the life of a project and alternative timing of capital expenditure, so as to arrive at an estimate of maximum present worth of the project.

Finally I turn to Sir Harold Hartley again. In reviewing the symposium he expressed his conclusions thus: 'What has interested me particularly in your papers has been their emphasis on control. This was the direct concern of most of them and was implicit in all, showing its significance in the optimization of modern processes both mechanical and chemical. Other aspects of plant design which were relevant to the title of this meeting received little attention except in the final papers. This emphasis and the sophisticated quality of the systems you discussed, confirmed my conviction that control engineering has reached the stage when it should be recognized as a primary technology. This has a dual significance. First control engineering must have its own teaching course. Then the control engineer must be a member of the design team from the outset; control must not be regarded as something to be added at a late stage of design'.

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Mechanical simulation units can represent loads in an elevator system and provide pilot 'feel'

Simulating absent units in aircraft systems

by **W. E. MAXWELL,**
Short Brothers and Harland

IN DEVELOPMENT WORK AND IN TESTING IT IS NOT possible always, or it may be inconvenient, to have all parts of a system operating together at the same time and under the dynamic conditions applying in actual operational use. For example, the normal aerodynamic loads on an aircraft elevator would not be present with the elevator control system operated on the ground, and in laboratory work the actual intertias and stiffness, etc., of the elevator system and control run in the aircraft would not be available.

This article proposes methods of operating a system in the absence of one or more elements, in such a manner that the system has the same dynamical behaviour as would be obtained with the element present. Provision can be made for systems with rotary and/or linear motions but, for simplicity, rotary motion is considered alone; the derivation of analogue systems with linear motion will be obvious.

The absent element may be any part of the system which has mechanical features. Normally it will produce a torque, comprising that derived externally (as in an electric motor), and components due to the inertia, stiffness, etc. of the element. Exceptionally, however, it may involve geometrical relationships in the mechanics of the system—such as cam operation.

When the absent element is a motor, or its equivalent, which supplies power to the system through its torque, power may be obtained from, say, an electric or hydraulic supply. In other instances the element may draw power from the system, and an electric or hydraulic load in which to dissipate it (examples are an electric generator and a hydraulic pump) will be necessary. The element may not be associated with an external power source or sink although it can supply or extract power for transient periods (according to whether it is decelerating or accelerating) because of the energy storage inherent in its inertia.

If the absent element is replaced directly with another unit, the latter will have to handle the full rated power of the element and this is the case in Method I, below. This means that in many instances, where duplicate units are available, a load unit identical with the driving unit may be used. Thus a servomotor may be loaded with an identical servomotor, operated in back-to-back fashion, in conjunction with computation.

Operation at full power may be avoided by producing the same effect as the absent element by more indirect means. Possible ways of doing this are described in Methods II and III, and these may be used where reduced accuracy of representation is permissible but not where the absent element is non-linear.

The absent element may have one mechanical coupling to the system only, or there may be mechanical transmission through the element from one part of the system to another. Accordingly the replacement unit should have provision for double-ended output.

While these proposals are more applicable to servo systems, it is not necessary that the motors, etc., in the complete system under investigation should be connected in servo fashion with feedback applied. They are applicable also to systems and components operated in an open loop manner. The motors shown in the diagrams would be servomotors usually.

METHOD I : Direct replacement by torque motor

Fig. 1a shows the absent element replaced directly

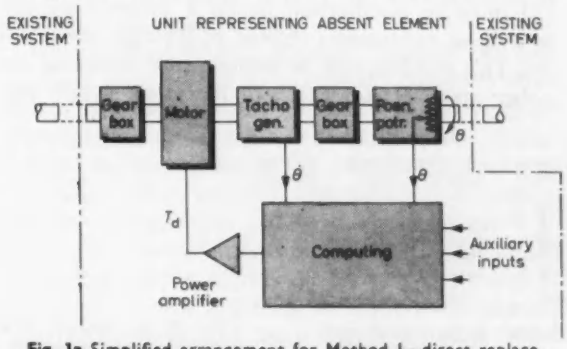
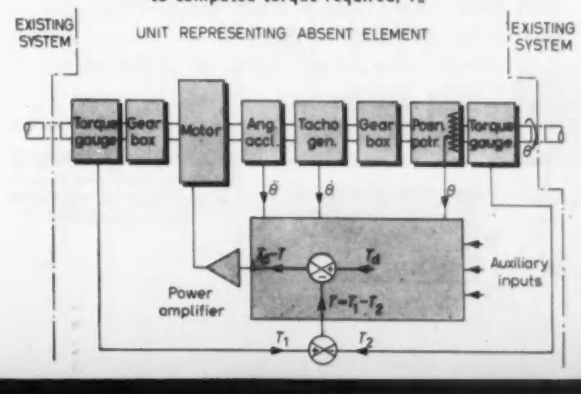


Fig. 1a Simplified arrangement for Method I—direct replacement of an absent unit with an equivalent torquemotor

Fig. 1b Comprehensive arrangement for Method I. Negative feedback ensures that torque developed T is equal to computed torque required, T_d



by an equivalent torquemotor unit, the torque being controlled by a power amplifier capable of supplying or extracting power equal to the full rated power of the element. A gearbox at each end of the shaft enables the torque/speed characteristic to be matched to that of the system for the power rating concerned. A range of gears of various ratios should be provided and the unit constructed for ease of interchange so that any torquemotor unit may be used for simulation within its power rating in any overall system.

The instantaneous torque required to represent the absent element is computed in the amplifier (or in part of an analogue computer) from the outputs of displacement and/or velocity pick-off devices, mounted on the shaft of the torquemotor unit, together with any other signals on which the characteristics depend.

Since the unit will have some inertia and resistance itself, these must be determined and due allowance made in the computing.

Fig. 1a illustrates a simple form of the system which should have quite general application. Refinements can be added, however, to give the fully comprehensive scheme of Fig. 1b. Here a negative feedback arrangement is used to ensure that the torque developed, T, is equal to the computed torque required, T_d. For this purpose a signal is provided from the difference in the outputs of two torque gauges measuring the torques T_1 and T_2 at the ends of the shaft. In a single-ended element one torque gauge only is of course necessary. An angular accelerometer is an additional refinement.

METHOD II : Auxiliary supply to existing motor

In the method of Fig. 2, a computed torque change is made in a motor (or, possibly, even a generator) which is normally connected to the absent element.

It may be inconvenient to use a torquemotor unit as a direct replacement because of the high power rating. This problem may be overcome by connecting the power amplifier in series with the motor supply and using it to alter the motor torque to the net value obtained on subtracting load torque from motor torque.

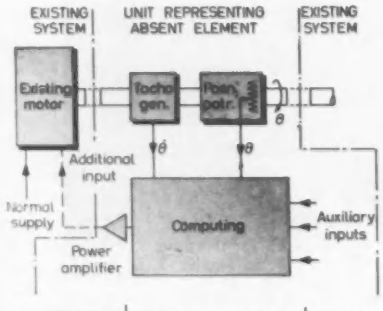


Fig. 2 In Method II a motor already in the system provides computed torque change

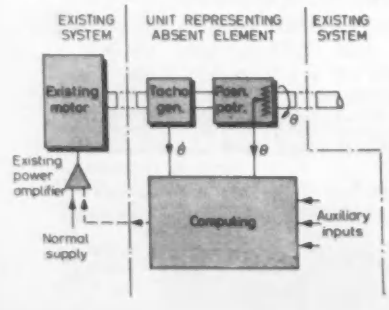


Fig. 3 Method III dispenses with both the torquemotor and its associated power amplifier

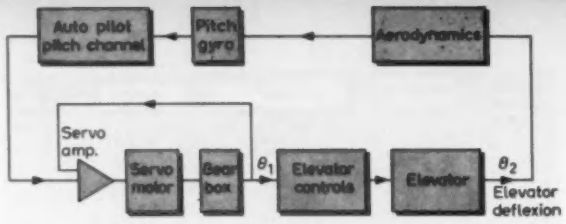


Fig. 4 The complete elevator control system

The replacement unit differs from that for Method I in that it contains no torquemotor. There remain only the pick-off device and gearboxes mounted on a shaft.

With the power amplifier operating directly in the motor circuit it must be capable of handling full rated power as for Method I. However, it may be possible to reduce the power involved by using a field circuit.

Since the power amplifier delivers a current appropriate to the computed torque required, the torque change produced in the motor depends on the relation between torque and current. If this is not one of simple proportionality, it must be such that allowance can be made for it in computing, additional signals being supplied for this if other parameters are involved.

METHOD III : Auxiliary signal to existing amplifier

If a motor is normally connected to the absent element and this motor is driven from an amplifier which also forms part of the system (see Fig. 3), it is possible to dispense with the torquemotor and associated power amplifier, leaving only pick-off devices and gearboxes mounted on a shaft and a low level computing amplifier feeding an additional torque signal into the motor drive amplifier in the system.

With this arrangement the power levels involved are negligible and if part of an analogue computer is available, no additional amplifiers are required.

As the computer provides a torque change signal to the motor drive amplifier, the torque change produced in the motor depends not only on the relation between torque and current at the motor but also on the characteristics of the motor drive amplifier. Thus the overall characteristics of motor and amplifier and any deviation from simple proportionality must be allowed for.

Motor

Normally, the motor used in the unit replacing the absent element would be an electric motor delivering a torque proportional to the input current. Although termed a motor it would operate at one instant as a motor and at another instant as a generator. Direct or alternating current motors may be considered, regardless of what is used in the remainder of the system.

A hydraulic unit could be used instead of an electric motor, especially where higher power, or rapid speed of response, is involved. The unit would normally give an output shaft velocity proportional to the input signal, so it would appear to be essential to use torque gauges in a feedback arrangement of the type mentioned in Method I. However, applied torque can be

obtained from hydraulic actuator pressure but a knowledge of other reaction torques in the replacement unit would be needed to determine the net torque.

Gearboxes will be required to match the torque/speed characteristic to that of the system with interchangeable gears, in order to cater for its insertion in different systems.

Power amplifier

Where an electric motor is used the power amplifier need not necessarily be an electronic amplifier, as magnetic amplifiers and even rotary amplifiers are possibilities. If a hydraulic unit is used, hydraulic power amplification can be employed, with electronic amplification at low power level only.

Computing

For convenience, flexibility and ease of adjustment to the prescribed characteristics, electronic analogue computation would normally be used.

If the characteristics involved are of a simple nature, the computing can be done in the amplifier providing the torque demand signal, but where they are more complex an analogue computer will be more convenient.

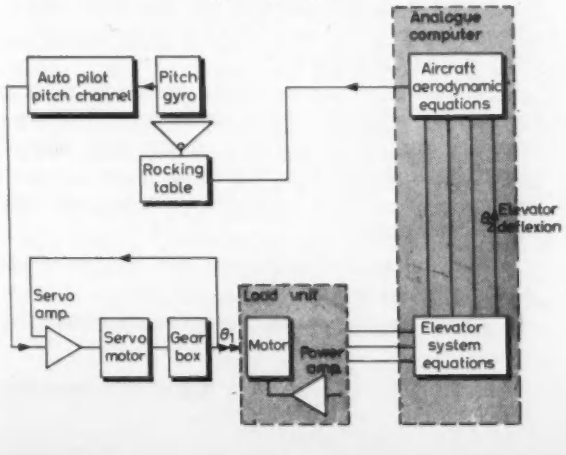
The author feels that these proposals are more likely to be of interest to those with a medium size transportable computer—e.g. the Short analogue computer. Part could be used for computing and, possibly, the remainder for simulation of other parts of the system.

Illustrative examples

An elevator control system. Consider the elevator control system for an aircraft (Fig. 4), where it is desired to operate the servomotor into a synthetic load representing the elevator controls and elevator—including its aerodynamic loading. At the same time, it is required to simulate the aircraft aerodynamics and impart a pitching motion to the gyroscope as if it were in the aircraft in flight.

The aerodynamic equations are set up on the analogue computer (Fig. 5), and a signal representing aircraft attitude taken to a rocking table with the gyroscope mounted upon it. The latter supplies realistic attitude signals to the autopilot which, in turn, operates the servomotor through the servo amplifier.

Fig. 5. Simulation scheme for the complete elevator control system of Fig. 4



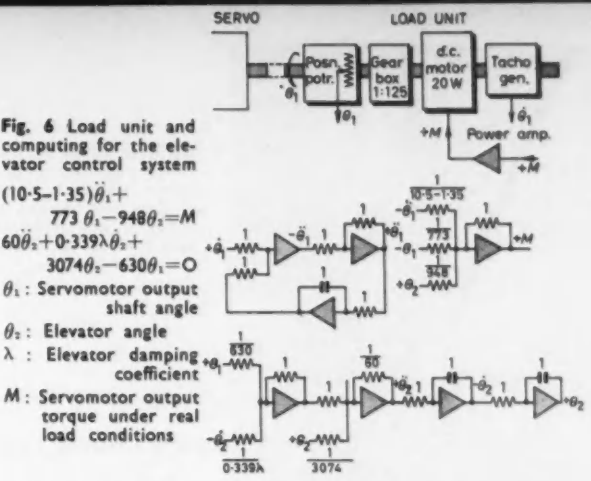


Fig. 6 Load unit and computing for the elevator control system

Following the lines of Method I the equations representing the elevator control system are set up on the computer, corrected for the load unit inertia, and used to control the motor in the load unit through its power amplifier.

Since the servomotor in the system is a 20-watt unit coupled through a gear ratio of 125 : 1, a motor of similar rating and gear ratio may be the load unit.

The load unit then is as shown in Fig. 6. Here also are shown the elevator system equations corrected for the dynamical characteristics of the load unit and the corresponding computer block diagram. In addition to a correct simulated load for the servomotor, the system provides a computed elevator angle signal for use in the aerodynamic equations which are also simulated but not shown.

Pilot 'feel'. These methods may be used to give a pilot 'feel' in his control stick.

The feel to be provided may be required to represent the reactions of the control runs and aerodynamic loads for an aircraft with direct stick control. This can be done in a manner similar to that for the elevator control system example (above) the servomotor being replaced by the control stick.

With powered control, however, the stick has only light operating loads and, in general, requires artificial feel to be applied from a mechanical arrangement representing the actual loads or desired synthetic characteristic. In development work where convenience of adjustment etc. is required, a motor could be used to generate feel after the fashion of the arrangement in Fig. 1a but further simplified. A small motor should be sufficient and a mechanical coupling is required at one end only. As a potentiometer may already be available on the control stick, the potentiometer on the simulation unit, together with a gearbox, may be omitted. It is possible also that the tachogenerator will be unnecessary, leaving only a geared motor in the assembly.

Although primarily useful in development work, these methods could be adopted for providing pilots with feel synthetically in actual aircraft installations.

Acknowledgment

The Author wishes to thank the directors of Short Bros. & Harland Ltd. for permission to publish this article, which is based on work carried out by the Research Department of the firm.

Reference

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Inspection equipment which forms an integral part of production flow lines has been designed by Kelvin and Hughes

by **J. BRIGG,** *Research Department, Kelvin & Hughes*

Advances in Ultrasonic Flaw Detection

THE MAIN ADVANCES IN ULTRASONIC FLAW DETECTION over the last few years have been in the design of machinery to manipulate both the material to be inspected, and the inspection probes themselves. The latest Kelvin-Hughes equipment is the result of 16 years research and development, and is designed to form an integral part of the production flow lines of high quality material and components. Increasing demands for high quality materials at high output rates require rapid and accurate inspection systems, and instruments similar to the type to be described have been used over the last two years.

Ultrasonic flaw detection depends upon the production of high frequency mechanical vibrations within the material to be inspected, these being generated by the application of pulses of high frequency electrical energy upon a piezo-electrical material. The resultant mechanical oscillations are transmitted through the test material as damped pulses of energy of relatively narrow beam width. On striking the opposite surface of the specimen, or internal discontinuities, a portion of the energy is reflected and picked up by the same, or a similar, crystal assembly which transforms the mechanical energy to electrical energy, this voltage then being amplified and applied to the Y plates of an oscilloscope. A time-base voltage, synchronized with the transmission and of sufficient duration to show the whole cycle of events, deflects the spot horizontally across the screen of the oscilloscope.

This enables both the thickness of the specimen and the relative position of the defects within it to be displayed on an oscilloscope. An operator, manipulating the inspection probe over the surface of the material under examination, may then interpret the indication shown on the cathode ray tube and thus determine the approximate position, area, size and orientation of the defect within the material.

Most existing ultrasonic testing equipment must be operated by relatively highly skilled and experienced personnel, for the prime duty of the flaw detector operator is to interpret results displayed on a cathode ray tube as defects of rejectable or acceptable level. The operator must :

a. Manipulate the probe over the surface of the material to be inspected.

b. Ensure proper acoustic coupling conditions be-

tween probe and material.

c. Periodically adjust the sensitivity of the flaw detector to compensate for changes in the testing condition.

d. Make notes of the approximate position and severity of all defects detected.

The disadvantages of this procedure lie in the operator's inability to carry out tests at an economic speed and the difficulty of ensuring a constant testing sensitivity. It is primarily with these two limitations in mind that Kelvin-Hughes' 'Autosonic' system was developed.

An automatic system must provide, at least, the following features:

a. An inspection speed equal to, or greater than, the output speed of the material to be tested

b. An automatic method of ensuring that the testing sensitivity remains constant over long periods

c. The automatic preparation of records showing the presence of defects in plan, depth and area

d. Operation and maintenance by semi-skilled labour

e. The entire inspection system should be capable of complete integration within a production flow line

The Autosonic system

For the purpose of this article, the Autosonic system may be divided into four major components:

1. Acoustic units or inspection probes
2. Electronic control system
3. Flaw indicating and recording equipment
4. Mechanical scanning system

Acoustic units

The inspection probes follow well established basic principles, any variations being normally confined to change in size and/or frequency. Both single and double probe systems may be used, the choice of system being generally governed by the shape of the component to be examined. A double probe system is ideally suited to the examination of large relatively flat areas such as sheet, plate, rolled and extruded bars, etc.

Double probes use the 'gap scanning' system. The acoustic couplant, generally water, is delivered to the probe system direct from the mains or via a circulating pump system. Fig. 1 shows a gap scanning probe holder which is mounted in a gimbal system so that it is free to take up any undulations in the surface of the material being tested. If the gimbal probe holder is supported by the piston rod of a pneumatic cylinder, remote raising and lowering of the probe to and from the surface is possible. This device can deal with plates of widely differing cross-sectional thickness.

Where the material has a complicated cross-section, a single probe system is used with the 'immersion scanning' system. The material is immersed in a tank of water and the working face of the testing probe maintained a specific distance away from its surface. This distance between probe and material is normally a

Fig. 1 A 60 mm wide gap scanning double probe, held in a gimbal mount. The gap for this probe is adjustable and irrigation water is fed to both sides of the probe

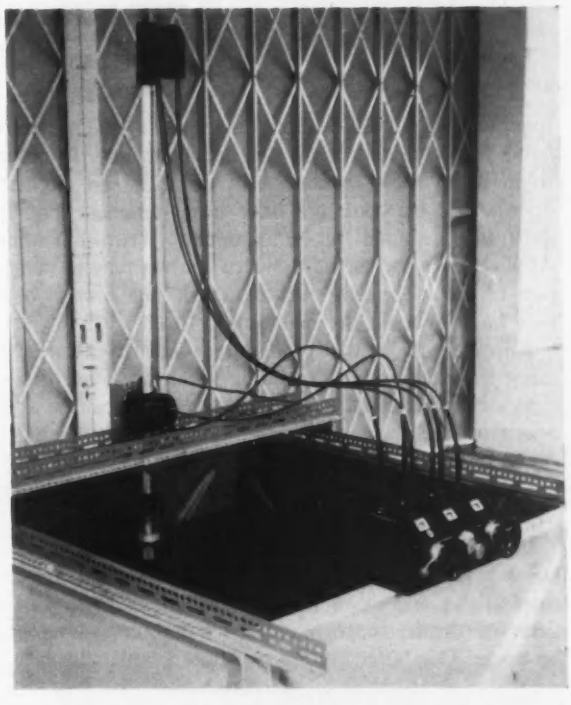


Fig. 2 The manually-operated three-dimensional probe manipulator, mounted on a slotted angle-iron bridge, with the control box on one side of the immersion tank

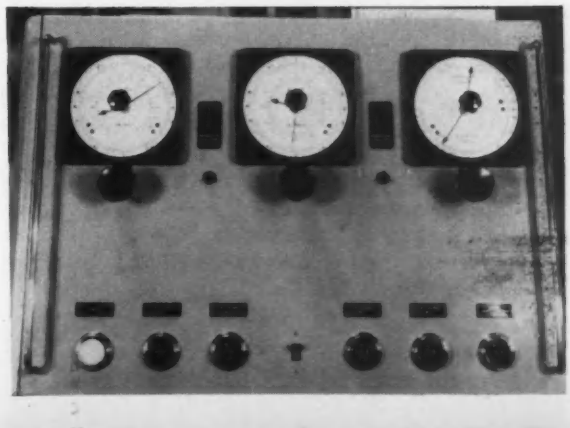


Fig. 3 The hand-controlled transmitter Magslip units for the servo-controlled probe manipulator are housed in the console

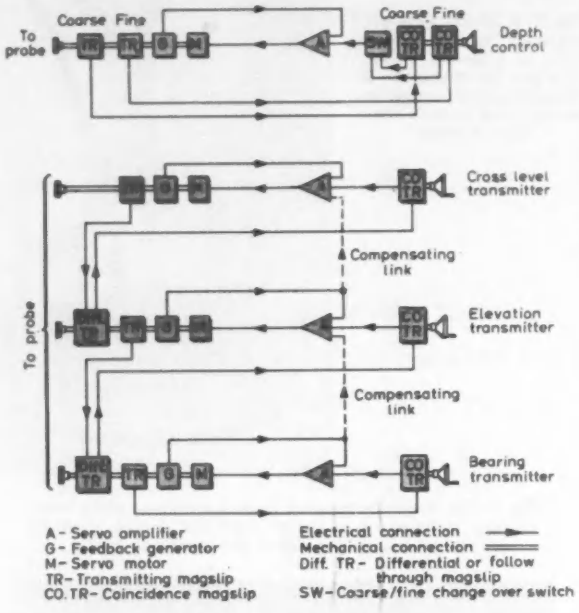


Fig. 4 Block diagram of the three-dimensional servo-controlled probe manipulator

function of the cross-sectional thickness of the material being inspected and/or the type of probe used. In order to maintain these conditions of distance and angular orientation, manipulators have been designed. Fig. 2 illustrates a manual probe manipulator (British Patent Application No. 12009/58), which enables remote variation of depth, bearing and elevation. The control box may be 25 ft from the manipulator itself.

Adjustments to the probe are made mechanically using Bowden cables. Operating handwheels move the cables over pulley wheels, so changing the position and orientation of the probe, these movements being indicated at the control box on engraved scales. The unit has a reset accuracy of better than 3° of bearing and elevation.

In order to overcome the limitations of operating distance and reset accuracy, a servo-controlled probe manipulator has been designed which enables variations of depth, bearing, elevation and cross-level to be made. This latter motion produces angular displacement at 90° to that of a given setting in elevation. These four motions are set from the control console (Fig. 3) by hand-operated Magslip transmitter units. Each motion is a full error voltage servomechanism using 50 V 50 c/s Magslip elements to sense the probe position (Fig. 4). Each Magslip train is fed to the input network of a 50 c/s amplifier whose output drives a small two-phase induction servomotor. Velocity feedback stabilizes each system, a miniature 50 c/s generator being incorporated in each motor for this purpose. The probe gearbox shown in Fig. 5 consists of three drives superimposed on one common centre necessitating a differential action between each to avoid interaction between them. A follow-through Magslip, driven by gears meshing with the bearing drive, has been added to the elevation circuit, so that, as the latter control turns, an exactly similar movement is applied to the elevation system. Similarly a wipe-out action by follow-through Magslip in the cross-level circuit has been arranged by meshing with the elevation gears. Use of the bearing control has the effect of preserving the other two settings by turning them in like manner.

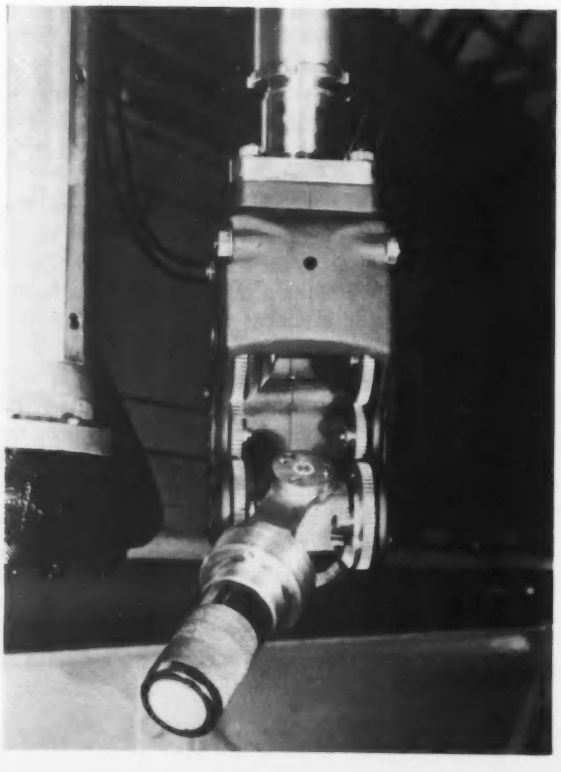
Either of these two probe manipulators allows orientation of the probe at an angle other than normal to the surface in order that shear or transverse waves may be generated in the material.

Electronic control unit

The heart of the electronic control unit is a conventional flaw detector. This generates pulses of high frequency energy, feeds them to suitable testing probes, and conveys reflected signals from within the material to an amplifier. This sequence of events is displayed on a conventional A-scope unit whose time-based speed is selected to display on the screen one sequence of events, i.e. the time taken from the point of transmission to the time of reception of reflexion from the back or boundary of the material. All reflexions from internal discontinuities appear as vertical deflexions between the transmission pulse and boundary echo and, therefore, the approximate size and depth of any defects are indicated in terms of amplitude of the reflected signal and its position along the linear time base.

Fig. 6 is the schematic circuit diagram for an automatic equipment having one flaw channel. Fig. 7 shows

Fig. 5 The gearbox of the probe manipulator, fitted with a single 30 mm diameter immersion probe



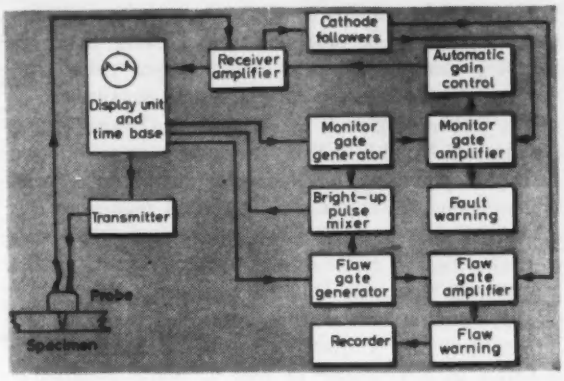


Fig. 6 Block diagram of a single-channel Autosonic equipment

a four-channel equipment with which it is possible to divide the material between the top and bottom surfaces of the specimen into four layers or strata, the output from each channel being fed to individual indicators and recorders. It is thus possible to vary the sensitivity of inspection in each stratum of the material. Such a multi-channel system is ideally suited to the testing of materials such as round bars, where the core or centre of the material is to be machined out at a later stage. It is unnecessary to determine the presence of defects in the centre region; therefore the channels would be set to ignore them.

Each channel consists of a gated amplifier whose operational position is made visible on the A-scope by brilliance modulation of the trace. These flaw gated amplifiers are triggered by pulses from the main time-base unit, which also initiates the transmission. The position and width of these flaw gates is continuously variable over the entire time-base range of the equipment. Only those signals which lie within a particular gate or channel are fed to its respective indicator and recorder. The output signals from these flaw gated amplifiers may be adjusted in order that signals above a predetermined amplitude will trigger the flaw warning relays. The recorders may be arranged to indicate the presence of all signals regardless of amplitude.

In order to establish a constant testing sensitivity despite changes in acoustic coupling, surface roughness or absorption characteristics in the material, a further gated amplifier selects a monitor signal (generally the boundary echo) whose amplitude is a measure of the testing sensitivity. If this varies, the monitor signal will vary, and hence d.c. potential derived from the peak amplitude of this signal will vary in proportion and is used to control the gain of the main amplifier. In conjunction with this automatic gain control system, a system fault warning device is arranged to operate a relay should the monitor signal fall below a predetermined minimum amplitude. This fault warning relay may operate visual or audible alarms and halt the associated scanning machinery.

Once the operator has positioned the inspection probe over the material, it is necessary only for him to set up the flaw and fault gates by observation on the A-scope. The output sensitivities of the flaw and monitor gated amplifiers are adjusted to conform to selected samples of defective material. He is then ready to start inspecting and little or no adjustment to any controls will be necessary, even for long runs. Any changes in cross-sectional thickness of the material under test will necessitate minor adjustments of the gate positions only.

Flaw indicating and recording

The eye is incapable of registering the presence of defects on an A-scope when testing at an economic speed, so recording equipment is necessary. Recorders have other advantages: they provide records, or certicates, to the purchaser of tested components; the records may be used by development personnel seeking methods of minimizing the occurrence of certain types of defect. The output of the flaw-gated amplifier is fed to indicator lamps on the console, and output sockets are provided for connexion into this circuit of other visual or audible alarm systems.

Servo-operated rectangular coordinate recorders, drum recorders, circular coordinate recorders, or straight line recorders may be used. A function plotting recorder where the X and Y (pen and paper) axes are operated by external potentiometers to produce a normal plan presentation record of the presence of defects in plates, etc., is fitted in the left-hand console of Fig. 9. The external potentiometers used to operate these recorders are driven by the longitudinal and transverse motions. They are 180-turn helical potentiometers (British Patent Application No. 34598/57), the drums of which are geared to make one revolution per foot of travel of the scanning machine.

Two scale expanders, one for each axis, enable recording at 1 : 1, 1 : 10, 1 : 25 and 1 : 100 scale of the actual plate. As the exact position of the plate within the scanning area cannot conveniently be maintained

Fig. 7 A four-channel Autosonic console, fitted with four Teledeltos straight-line high-speed pen recorders and a 35 mm camera for photographing the A-scope presentation

Fig. 8 A 20 ft × 12 ft Autosonic scanning machine with three-dimensional servo-controlled probe manipulator attached to the probe carriage

to very fine limits, a decade box is included in order that a backing-off voltage may be applied to the recording system, thus bringing the start point, or corner of the plate, to coincide with the top left-hand corner of the recorder chart. This system provides a recording accuracy of better than 1%.

In all these recorders the pen makes a mark on reception of the flaw signal. The writing system can, however, be reversed to give a mirror-image recording, the pen writing when there is no flaw and leaving clear paper when flaws are being detected.

If the amplitude of the flaw signal must be recorded, as well as its position within the material, high-speed galvanometer pen recorders are used, the deflexion of the pen being proportional to the amplitude of the signal. The paper drive system would be servo connected at a fixed ratio to the motion of the probe or material.

Automatic preparation of a written record may not be justifiable and, in such instances, an automatic flaw marking device is built in to the probe holder. This is an electropneumatically operated device which leaves a semi-permanent coloured mark on the surface of the material adjacent to the defect detected. This system is actuated via the flaw warning relay. Thus, a plate may be examined and, if found to have marks on it after test, would be cut in such a manner as to leave the defective part in the rejected areas of the plate. This automatic plate marking system is designed to operate in both gap scanning and immersion testing systems.

Mechanical scanning units

These are designed to move probe or material in a predetermined pattern in order that the material may be examined completely, or be given a percentage inspection. It follows that they must be capable of inspecting the material at a speed equal to, or greater than, the speed of production.

The machine must cater for a great variety of scanning areas and be adaptable to existing materials handling methods, such as power driven roller conveyors, or constitute a complete testing installation.

The Kelvin-Hughes (Fig. 8) machine (British Patent Application No. 12010/58), provides movements in two planes, longitudinal and transverse, at speeds between 1 in./min and 150 ft/min. An important feature of this machine is that it provides two motions, at right angles to each other, in either direction, at any speed, at the same time, from one stationary motor.

The scanning unit may be controlled either locally or remotely, full control being in the hands of the operator at the console in Fig. 9. While material is being delivered to and from the testing site, or during maintenance, the console operator can use a local control panel situated at one end of the transverse bridge. Only essential controls are available on this panel. The scan selection and setting controls are all housed in the console, with the speed control units.

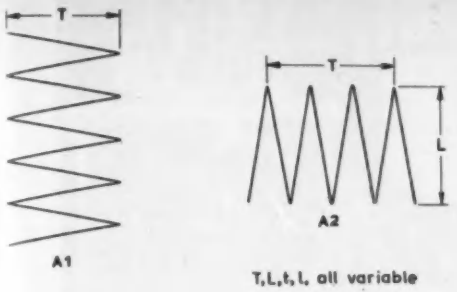
Any one of four scanning patterns (Fig. 10) may be selected and these are variable in pitch and amplitude. These scanning programmes may be preselected and set up for individual material sizes. The choice of scan pitch is usually decided by the width of the probe, the percentage inspection required, or the size of defect to be detected.

Fig. 11 shows a cut-away perspective view of the complete mechanical system. The unit consists of longi-

Fig. 9 Control console for four-channel Autosonic scanning apparatus. The centre unit houses all the control equipment for the mechanical scanning unit

tudinal cast iron running rails, supported by fabricated pedestals. Along these rails run the bogie units which in turn support the transverse bridge. The probe mounting plate is suspended from running rails within the bridge structure. All movements are produced by chain drives from the main motor box.

The motive power is supplied by a 3 h.p. motor which drives the input shafts of two Carter hydraulic gearboxes. The output speed of these two boxes is remotely controlled from the console. Their output shafts drive into two identical forward/reverse two-speed gearboxes, which are operated by magnetic clutches to drive



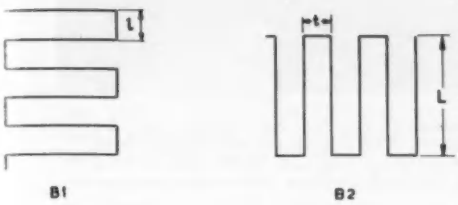


Fig. 10 The four basic scan patterns which may be preselected and set by controls within the console. All parameters of these four scan patterns are continuously variable within the scanning area of the machine

the chain system. The longitudinal drive chain moves the bogie units along the rails, and the transverse drive chain moves the probe mounting plate. This motion is transferred to the bridge via a bevel gear arrangement to a second chain loop on the bridge.

As the drive is supplied to one side of the machine only, two fixed datum chains are provided, one on each rail. These are connected by a tubular cross shaft to ensure that no 'crabbing' of the bridge can take place. The two datum chains are matched in length and fixed at each end of the two rails. It is from these two chains that all measurements are made to determine the scanning patterns and the precise probe position. The probe position is indicated to within 1/10 in. by counters on the bridge and console.

The entire system is designed to 'fail to safety' in the event of accident or power failure, the main motor being switched off and spring-loaded brakes applied to each motion. All the main controls are electrically and mechanically interlocked.

If it is desired to test rolled bars, etc. one longitudinal rail only is used and the probe mounting plate is held on one of the bogie units. This plate is capable of moving approximately 2 ft transversely, being powered by an inching motor unit. The scanner would be situated along one side for an existing powered roller conveyor.

Any of the probe handling units, referred to previously, may be attached to the probe mounting plate. The coaxial probe signal leads, control leads, pneumatic supply lines, water, etc. are carried within the machine itself, by cable carriers in such a manner that only flexure takes place. (British Patent Application No. 10819/56.)

For the inspection of extruded, or cast billets, it is desirable to rotate the material through a given arc and then scan longitudinally the axis of the billet. This billet rotating unit operates completely immersed in water. In principle it consists of two V-blocks with knurled rollers to support and rotate the billet. These rollers are actuated by a pneumatic torque converter unit. The increment of rotation is variable so that a prescribed number of scans may be made over billets varying in diameter between 2 in. and 30 in. A duplicate, but undriven rotary V-block, is situated at the other end of the tank to support the billet.

In the case of circular sections, i.e. turbine disks, wheels, etc., it is usual to rotate these on a turntable, and to carry out a series of concentric scans or one helical scan.

All scanning and rotating units are fitted with servo transmitters which operate the various recording units.

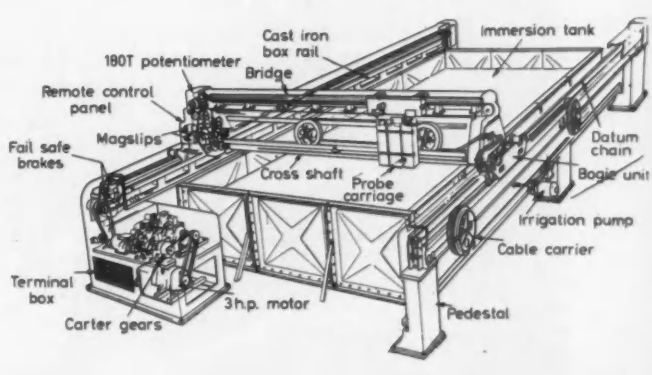
Some practical installations

This brief description covers the basic aspects of an automatic non-destructive testing system, which can be integrated into most production lines. It is capable of operation by one man. Complete records of all tests are immediately available.

Installations similar to those described are in use for the automatic inspection of cast aluminium alloy billets. These are delivered to the inspection site direct from the casting machines, after which they are cut up into extrusion lengths and the known defective parts of the billets discarded prior to extrusion. Equipments are also in use for the examination of extruded heat resistant alloys destined for the manufacture of turbine compressor blades. An installation has been completed for the detection of laminations in the shell plates of atomic energy reactor spheres. Within the next two months installations will be made for the automatic inspection of rolled steel bars up to 8 in. in diameter, and for the inspection of cast aluminium alloy rolling blocks.

In the author's opinion this system provides a major step forward in quality control; yet its use would increase the cost of the product by a very small percentage only. In the search for quality, this small 'on-cost' would be fully justified. It must be remembered that material rejected by these tests can, in the majority of cases, be relegated to other, less critical, uses. Only very occasionally would it be necessary to class it as scrap.

Fig. 11 Cut-away perspective view of an Autosonic scanning machine



CONTROL IN ACTION

Colman study autocontrolled check weighing

Initial installation ensures accuracy

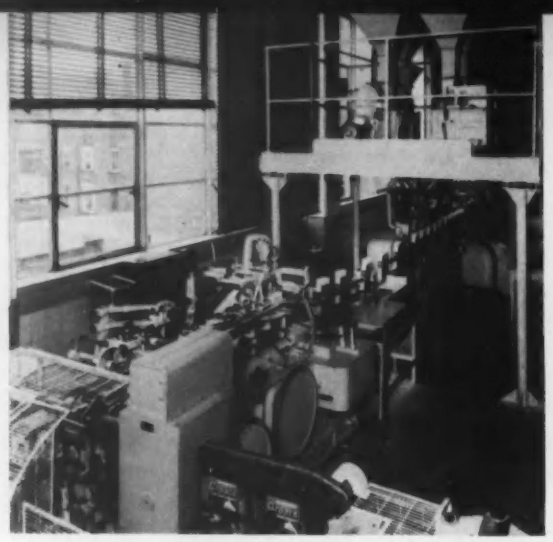


Fig. 1 A production line for 'baby cereals' at J. & J. Colman's Carrow Works. Note the four hoppers feeding the net weighers, followed by a Solartron net weigher and, foreground, a Rank Cintel metal detector

IN THE FOOD INDUSTRY CHECK WEIGHing—the weighing of a packet of food after it has been filled with its nominal weight or volume of product—appears to be a necessity. It is of primary importance that the customer who purchases a packed food product should receive not less than the stated quantity. This is, of course, bound up with the problems of good customer relations upon which the food manufacturer is so dependent, quite apart from any legal implications in which a statement of net weight may embroil the seller.

So far as foodstuffs are concerned, there is little danger to be expected from giving overweight, although from the economic viewpoint it could hardly come under the heading of good business practice. Indeed, it is sometimes suggested that the more responsible manufacturer is prepared to accept some slight loss if he can be certain that by so doing he will never give underweight.

Why weigh twice?

Most foodstuffs in powder form may be fed into their containers using a beam balance weigher—the *net weigher*. Unfortunately, many of these products are slightly sticky and may tend to adhere to the sides of the hopper, so leading to under- and overfilling. Previously the conventional method of check weighing was to reweigh a proportion of the open packs —or even every pack—so that adjustments could be made to the net weigher.

This manual checking not only is wasteful of labour but acts as a brake on the usefulness of the more modern high-speed machinery which is now being increasingly installed.

J. & J. Colman, of Norwich, produce a variety of foodstuffs at their Carrow Works, and they have found the high-speed check weighing problem particularly difficult with the precooked cereals which they market, primarily, for infants. These 'baby cereals'—Robinson's Patent Groats, Baby Rice and Robrex—are in powder form although, possibly because of the physical properties and hygroscopic natures of the products, they behave at times more like a viscous semi-liquid than a powder. Occasionally the product will stick to the sides of the feed hopper so that certain packs may be underfilled and subsequent packs overfilled.

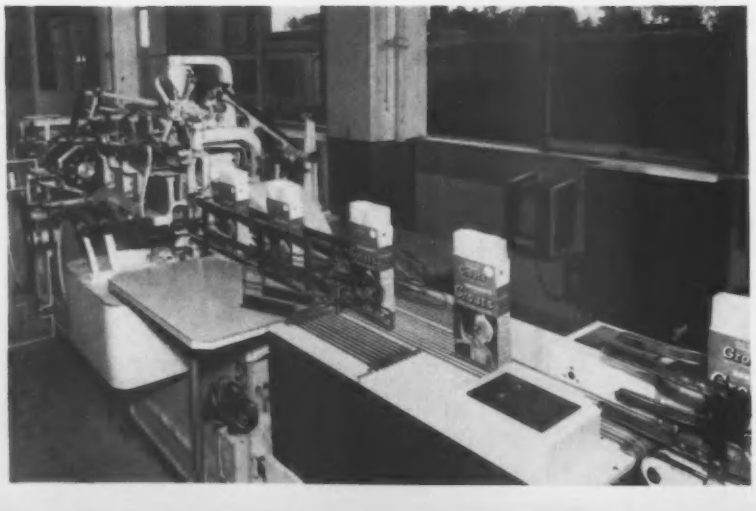
The development of a high speed automatic check weigher by Solartron Industrial Controls *(1)* gave every promise of a solution to the problem —as well as an opportunity to study the possibilities of automatic weighing control. Accordingly, Colman have installed an automatic check weigher.

The production line

Fig. 1 gives a general view of the line, flow being from the rear to the foreground of the photograph. First, the packets and their inner liners are formed and these are filled in batches of four under the control of the four net weighers. The packets are check weighed, those underweight or overweight being diverted off the line. The packets passing the check weigher have their lids folded and glued and are then passed through a Rank Cintel metal detector and finally packed in outer cases for dispatch to customers.

The four feed hoppers for the net weighing system, which is by Southall and Smith of Birmingham, are at the top and to the right of Fig. 1. The conveyor belt is synchronized with the net weighing system, the packets themselves causing the net weighers to tip the product into them. The four net weighers provide a coarse feed followed by a trickle feed to give the required net weight of product.

Fig. 2 Close up of the check weigher at Carrow Works. One packet is on the weighing platform



Check weighing

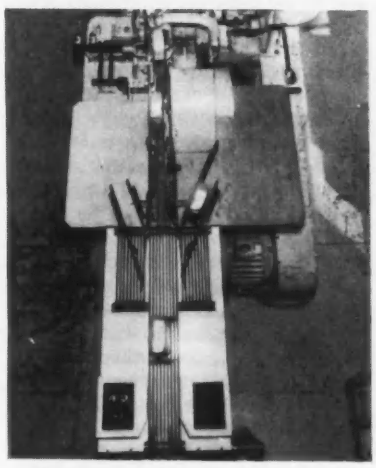
Fig. 2 shows the Solartron check weigher. The filled packages pass on to the weighing platform which rises, so halting the packet's progress during check weighing. Fig. 3 is a view from above of the weighing platform and shows the three alternative paths which a packet may take after weighing:

overweight to the right, correct (within tolerance) straight ahead, and underweight to the left.

As each packet enters the weighing platform it interrupts a beam of light to a photocell, so providing a signal which causes the weighing head to rise and thus lift a packet. The check weighing system employed is of the electromagnetic force-balance type, whose operation will be apparent from the simplified diagram of Fig. 4. The weighing platform is mounted on a shaft which is free to move vertically although restricted in lateral movement. The shaft carries a coil which moves in the gap of a permanent magnet, and a shaft-position detector is also incorporated. As the platform falls under the weight of a filled packet, a signal from the position detector causes d.c. to flow through the coil so providing an upward electromagnetic force. Equilibrium is established between downward force—weight—and upward force, the current through the coil being a direct measure of the weight.

Coil current is passed through a precision resistor to give an output voltage proportional to weight, and this voltage is compared with a standard voltage in the control equipment shown on the right in Fig. 2. An error voltage is thus obtained, and this is amplified and caused to drive a centre-stable polarized relay. The contacts of this relay close in one or other direction to indicate high or low weight, but remain open over the correct weight zone. The relay controls 'high' 'correct' and 'low' weight and also controls a solenoid on the mechanical handling unit which is arranged to eject underweight and overweight packets.

Fig. 3 The check weigher viewed from above. Note the three routes: over, correct and underweight. An overweight packet has been diverted to the right



Experience at Carrow Works

Colman appear to be very well satisfied with their check weighing installation, although they see it as just the beginning of a move towards fully automatic weighing as distinct from check weighing alone. The suggestion is that it may be possible to arrange for a check weigher to feed back to, and control, volumetric screw type fillers. Colman's Chief Engineer, Mr. P. S. O. Durrant believes this to be possible and CONTROL understands that Solartron hope to announce something along these lines very shortly.

As is usual with installations of this nature it is very difficult to get actual figures for any savings made. The main potential saving is in material and stems from the fact that the operator has a visual incentive to correct the net weigher if the check weigher rejects more than a few packets as overweight. This facility is, of course, available using conventional check-weighing techniques, although the automatic check weigher does give an immediate indication of an overweight setting, and drives this fact

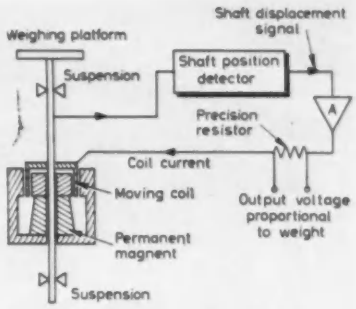


Fig. 4 Simplified diagram of the Solartron automatic check-weigher

home by diverting all overweight packets from the main stream. Possibly there is some improvement in productivity, in that the production line is allowed to operate at optimum efficiency, as automatic check weighing should free the line from the bottleneck which can occur with manual weighing.

These advantages are appreciated by Colman's Production Department but they see the true value of the equipment as a form of insurance against erratic weigher performance. It gives them a sense of security. In the past every potential consumer complaint (an inspection term employed at Colman's and related to the fraction of an ounce which a packet could be underweight) was viewed with concern. Now, their figure for potential consumer complaints is zero.

Acknowledgment

is made to J. & J. Colman Ltd., for permission to publish this article and to Mr. P. S. O. Durrant and his staff for help in preparing it.

Reference

1. Hendon, A. L., and Chapman, G. C.: 'Weighing Techniques for Automatic Production lines,' *Transactions of The Society of Instrument Technology;* to be published. This paper is summarized in 'Automatic Weight Control,' *Control,* 1959, *2* (March), p. 87

CONTROL IN ACTION

Control at the Heinz Kitt factory

45 retorts automatically regulated

by A. Danielsson, Manager—Application Engineering Dept., Taylor Controls Ltd.

A NOTEWORTHY FEATURE OF THE NEW H. J. Heinz factory at Kitt Green, Manchester, is the automatic control of the canning retorts. Heinz decided their canned products should be processed in batch type retorts, rather than in a continuous type of cooker, because of the flexibility of the batch retort as regards can sizes, processing variables, quantities of one product being processed, etc. The batch retort enables the plant to be expanded in any direction and in any size increment according to the demands of the consumer market for certain types of products.

Giant retorts

Initially the factory comprises two departments, one devoted to soups and the other to baked beans in tomato sauce. The retorts, the largest ever used for can-processing, are like giant locomotives (Fig. 1) and each has a capacity of 8000 cans of 16 oz size. There are also retorts of half of this capacity for lesser production quantities and for handling the smaller

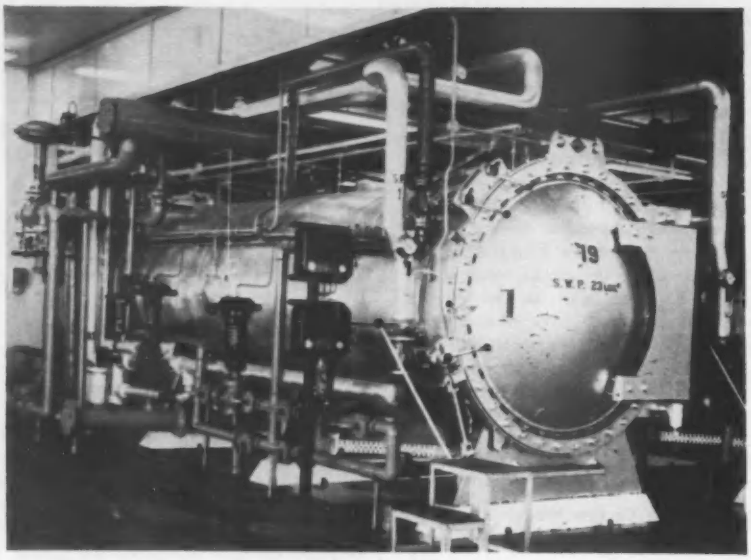


Fig. 1 A close-up of one of the retorts showing the pressure and temperature transmitters, with some of the diaphragm-operated valves in the background

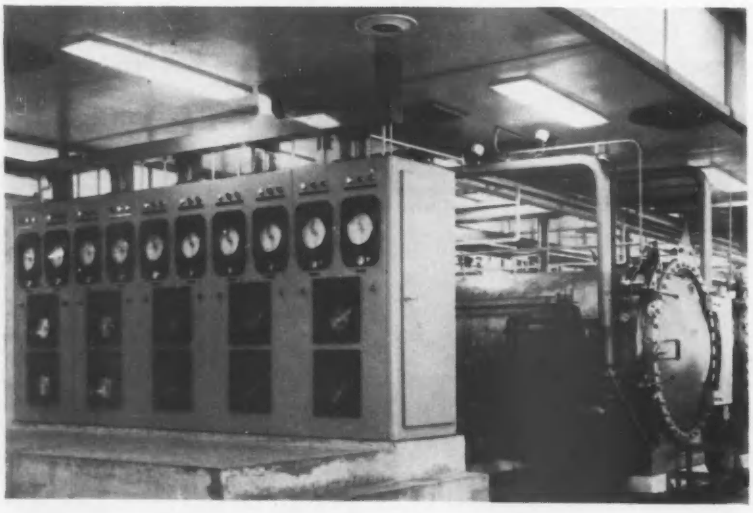
quantities involved at the end of a run. Before the first 37 retorts were installed — the initial installation — it was already envisaged that more would be required to handle the market demands, and a further eight were installed and commissioned before the official opening on May 21. This makes a total of 45 retorts with a total handling capacity of over a million cans a day.

The retorts are horizontal with a single door and are loaded by fork-lift trucks, there being eight crates in the large retorts. Loading of the crates with cans is semi-automatic, cans being delivered from the filling and seaming machines at the rate of 350/min.

Centralized controls

Because of the high quality of product required by the firm of Heinz, it was inevitable that the retort processing operations had to be fully controlled automatically from start to finish. No expense was spared on the instrumentation. A plant was envisaged in which all control instrumentation was centralized, remote from the retorts, so that the operator's only concern was with loading and unloading the retorts as directed by signal lights, the initiation of the processing being from the centralized control panels by a supervisor. The control equipment is by Taylor Controls Ltd.

Fig. 2 A section of the bean processing plant. The panel carries the temperature-pressure controllers and timers for 10 retorts



Remote transmission

In some instances the retorts are up to 200 ft away from the control panels, and so pneumatic transmission was used for the process variables, i.e. temperature and pressure. The transmitter lines as well as the control lines are of plastic tubing installed between the panels and retorts, and carried in trunking in a mezzanine floor, above the retort room. This carries all piping associated with the process, thus keeping the shop ceiling void of any untidy pipe work. A section of the bean processing room is shown in Fig. 2.

The process

After loading and closing of the retort door, steam must be admitted to raise the retort temperature as quickly as possible. In order to obtain uniform heat distribution, the retort must be thoroughly vented, i.e. all the air inside the retort must be expelled so that (1) there are no pockets of air to give false temperatures; (2) the pressure and temperature relationship is that of saturated steam; and (3) the condition outside the cans is the same as the condition inside. The venting step is extremely important with vessels of this size, as the slightest variation in temperature along the length of the vessel cannot be tolerated for a uniformly processed load.

After venting, the retort temperature is increased to the processing temperature and then automatically timed for the 'cook' or sterilization duration. Timing also is important as, when processing at a relatively high temperature, a small variation in the process time can considerably change the resultant cooked product. The prime factor in this operation is sterilization of the product and the cooking, is, in fact, incidental although perhaps of greater apparent importance to the user. At the end of the cooking period, the steam must be shut off and the retort rapidly cooled by admission of cold water to prevent over-cooking. At the same time, the retort pressure must be maintained by the admission of compressed air, so that the internal pressure still present in the cans cannot cause damage to the can walls or seams. Conversely, as the cans cool, the external pressure must be relieved for similar reasons. The cooling then proceeds until the cans are cold enough to handle, yet sufficiently warm to dry their external surfaces prior to labelling.

Types of instrument

The prime elements of the control system are the Fulscope temperature and pressure controllers contained in one case, and the Flex-O-Timer programme controller which maintains the strict time control over the process and initiates all the sequence changes. Temperature and pressure are recorded on the same chart to give a permanent record of the processing of each batch.

Safety interlocks

After the retort door is closed, the operator manipulates levers to turn on the main steam and water supplies. These three functions operate limit switches to complete a circuit to the control apparatus, and also illuminate a signal light at the control panel to signify that the processing cycle may start. As soon as the panel supervisor operates the start button an electropneumatic interlock is operated on the retort door so that the door cannot be opened until the cycle is complete and the interlock released. Further signal lights indicate when the cycle is on and when it is complete. These are duplicated on the instrument panels and at the retorts.

In the event of electrical failure the retort door locks and the cycle stops in the condition it had reached at the point of failure. Manual controls are provided so that the retort can be brought down by hand, without loss of production.

Cooking cycle

The control system is shown diagrammatically in Fig. 3. Operating the start button actuates the Flex-O-Timer, which immediately opens the steam valves. The drain is held open for a few minutes in order to relieve the initial condensate which is subsequently handled by a conventional steam trap.

The retort is then vented according to the National Canners Association's recommendations, which stipulate that a vent valve must be held open to atmosphere for 8 min and until a temperature of 220°F is reached, whichever is the longer period. When these conditions are fulfilled, the vent valve is closed and the retort temperature is raised to the set-point temperature of the controller, at which point the cook time period is initiated. Owing to the greatly varying steam demands of the retort during the coming-up period and the cook period, two steam valves are used. When cook temperature is reached, one valve is closed, a smaller valve effecting accurate control of temperature.

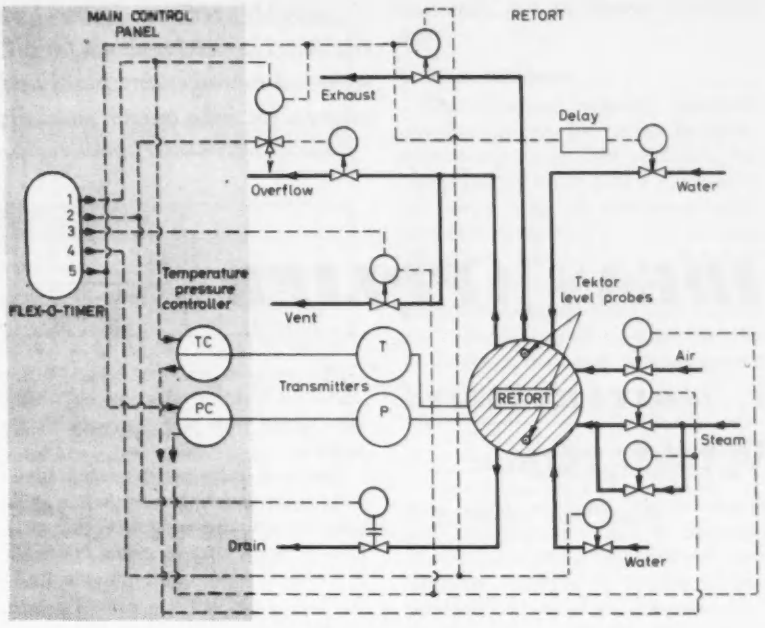


Fig. 3 Schematic of retort control system. Pneumatic control signals are represented by dotted lines

Cooling cycle

At the end of the cook period the steam is shut off, and water is admitted at both top—via sprays—and bottom of the retort. This gives rapid filling of the retort and uniform cooling. A level probe is used to determine when the retort is full of water, and at this point, the top water is shut off and the cooling is continued through the bottom valve alone. The pressure controller is in operation during the retort filling period only and is coordinated with the entry of the water so that the cans are not subjected to any external pressure change. By the time the retort is full of water the internal pressure of the cans has dropped sufficiently for the external pressure to be relieved without danger.

The retort contents are cooled to a predetermined temperature, after which a prolonged cooling period is imposed in order to dissipate all the internal heat from the cans. The duration of this period varies with the size of the can being processed and the nature of its contents.

Finally the water is turned off and the drain opened, but the cycle is not complete until the retort is completely drained. This is determined by another level probe, in the bottom of the vessel, which causes the timer to reset and release the door interlock.

The drain and overflow lines are all piped away to recovery plants and the vents are piped to atmosphere, thus keeping the retort room completely dry and free from water vapour.

Blanching

Another important instrumentation feature of the Kitt Green plant is the control on the bean blancher. Blanching is the first process applied to the beans after initial electronic sorting and prior to their passing through the infrared baking ovens. The blancher is a continuous pipe type and consists of a series of pipes joined together to form one long pipe through which beans and water flow. Steam is injected at two stages along the pipe to raise the temperature to a predetermined level and hold it there for a period determined by the velocity at which the beans flow through the pipe. Temperature control is effected by two ratio controllers, one at each steam injection stage. The first injector acts as a coarse controller for the second stage. The temperature at the outlet of each injector is controlled and the adjusting system of each ratio controller is installed before the inlets of the heaters. Thus any change in inlet temperature of the product is compensated for on the controlling system so that the outlet temperature is unaffected.

Numerous other controllers exist at various locations on the plant, e.g. level controllers on feed tanks and temperature controllers in heat treatment; all play an important part in the manufacturing process.

A monthly review—under basic headings—of the latest control engineering developments for all industries; specially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are not specialized in instrument and control systems

IDEAS APPLIED . . .

. . . to DATA HANDLING

The multi-turn digitizer

D. S. EVANS, Hilger & Watts

Single-rotation digitizers have been described in earlier publications, but little has been said about geared units and the additional problems entailed. It is intended therefore, to describe one such system with which I am most familiar and to indicate the usefulness of the multi-turn digitizer with particular reference to precision length measuring machines.

Ambiguities in geared systems

When coarse and fine scales are used in conjunction with each other, as on a micrometer, domestic gas meter or magslip transmission system, doubt arises at changeover points as to the correct reading of the coarser scales. We are all familiar with the situation. The observer has to make the decision by referring back to the

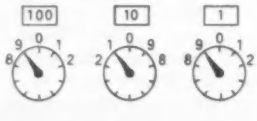


Fig. 1 Ambiguities in reading a gas meter type dial can only be avoided by reference to lower significant values

lower significant scale in order to assure himself that a higher or lower number has to be read on the coarse dial. An example is shown in Fig. 1. This uncertainty is due partly to the coarseness of the scales and to the inaccuracies in the gearing between the scales. On a bi-directional counter backlash has to be overcome.

Automatic selection of coarse readings

The method used to overcome the errors mentioned above in a system comprising two digitizers geared together is to provide the coarse digitizer with two scales (Fig. 2). Since both scales are identical this may physically be a single scale with two sets of detectors.

The two scales are displaced angularly from each other by half a division and are aligned with the fine scale in such a way that when the fine scale is about to return to zero, the leading coarse scale is a quarter of a division in the next higher number, whilst the lagging scale has still a quarter of a division to go in the lower number. The choice of the coarse scale to be read is determined by the fine scale and depends on which half of the revolution it is in.

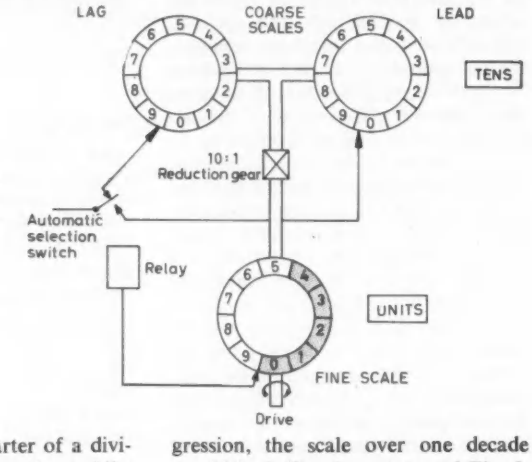


Fig. 2 To avoid ambiguities the change in unit readings (9 to 0 or 4 to 5) can be made to choose the tens reading

If in the example the fine scale is reading say 9, the lagging scale will be chosen and the result will be 99. If however the fine scale is turned to 0 the leading scale will be chosen so that a sudden change from 99 to 00 will occur without ambiguity.

Choice of scale

For reliability the digitizer uses a binary or yes-no coding system. The choice of the code is most important since a wrong choice can make decoding difficult, cause ambiguities in reading off a single scale and possibly between two scales.

In order to be able to translate easily to decimal the decimal breakdown is preserved in numbering the scale. In other words each decade is taken piecemeal and coded in the binary form. This is referred to as BCD, or binary coded decimal. In its simplest form, a normal binary progression, the scale over one decade would look like the pattern of Fig. 3, where the shaded portions represent ones, and the unshaded zeros. If the scale is metallic, then the ones can be

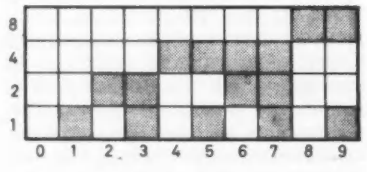


Fig. 3 Binary coded decimal. Each decade in a decimal scale could be encoded in this form but for the possibility of errors at transitions

represented by conducting sections and the zeros by insulated sections.

A simple relay switching circuit can be made to translate the binary back to decimal by having a row of contacts bearing on the scale, such that

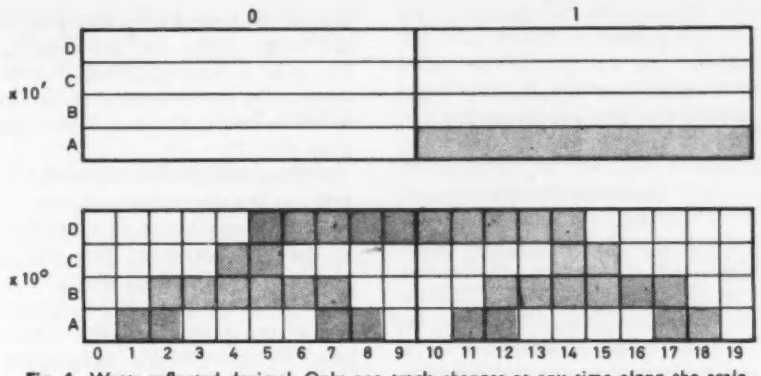


Fig. 4 Watts reflected decimal. Only one track changes at any time along the scale, so avoiding ambiguities

each contact detects the elements of a particular row.

Avoiding ambiguities on a single scale

Unfortunately, the simple BCD code shown will produce erroneous readings at the changeover points between one number and the next, where more than one change has to take place, since the contacts will not pass over the boundaries simultaneously. This is like going from say 999 to 000 on a decimal counter. Unless all the figures are made to change together different combinations can result.

One method of avoiding these ambiguities is to permutate the four binary digits of each decade to produce an arrangement which only allows one binary digit change to occur at any one number change throughout the whole of the scale. The WRD or Watts reflected decimal is such an arrangement, and it is shown in Fig. 4. Translation of the WRD code can be done in a similar fashion to that shown for the ordinary BCD but it should be noted that reference has to be made to the next higher decade, since without this tie-up the numbers would come out as 0 to 9 and then 9 to 0 alternately. If the previous decade is odd a correction is made. This adds but little more complexity to the decoder and in fact merely requires the reversal of the D row to put it right. For this reason the row is sometimes referred to as the complementing row.

WRD scales in a geared system

If now the arrangement of Fig. 2 is reconstructed with scales having a WRD code, the relationship between the coarse and fine scales can be seen (Fig. 5).

It should be noted that the scales are in themselves non-ambiguous, but apart from this the part played by the D row of the fine scale is worthy of note. As well as serving as a complementing digit it decides the change from 9 to 0 or 999 to 000 (depending on the number of decades on the one scale) and also chooses the leading and lagging coarse scale readings. There is therefore an absolute tie-up between the readings on coarse and fine scales and all change simultaneously.

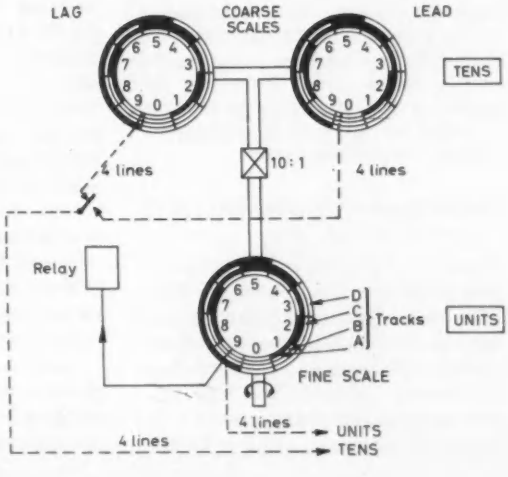


Fig. 5 The D or complementary track of the fine coded scale decides the change from 9 to 0 or the units, and the corresponding number change on the coarse scale

Backlash tolerances

The choosing system described therefore allows for errors in transmission due to backlash and other imperfections of up to half a division on the coarse scale. So that on a multiturn arrangement of say 1000 fine and 100 coarse scale giving a total scale length of 100,000 in 100 turns, the maximum backlash allowance is about 1·8°, which is quite manageable. For a 10 times scale the tolerable error can be about 18°.

(to be continued)

. . . to DISPLACEMENT

A technique from Russia

In the first issue of *Instrument Construction* the Russian monthly journal translated by BSIRA, there is a short account of a new method of small displacement measurement.

A theory is developed by the author, A. Yu Gudel, to show the relationship between the thickness and the diameter of a drop of liquid compressed between two plates. It is essential that the liquid does not wet the plate material. As the liquid disk thickness decreases the diameter increases rapidly, so that between thicknesses of 0·010 mm and 0·005 mm the amplification is about 1900. This means a change in thickness of 1 micron corresponds to a change in diameter of about 2 mm.

An instrument is described using this principle in which a drop of mercury is compressed between two parallel quartz plates. The top plate is fixed and the bottom one is free to move in a vertical direction, being coupled to the displacement which is being measured. The change of the disk diameter is made by a microscope or an optical projecting system.

. . . to INSTRUMENT DESIGN

Vibration of lightly-loaded spring systems

P. G. MORGAN, University of Manchester

The frequency of vibration of a mass, simply supported by a spring of known stiffness, is easily calculated from first principles. For a more accurate determination of the frequency, it is necessary to make an allowance for the mass of the spring itself; this is

usually performed by Rayleigh's method, in which any reasonable deflexion curve for the spring-mass system, e.g. the static deflexion curve, is assumed and used for the calculation of the fundamental frequency. Applying Rayleigh's method to the system of Fig. 6, one may easily show that the effect of the mass of the spring may be taken into account by adding

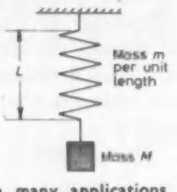


Fig. 6 In many applications it is not sufficiently accurate to take the equivalent mass of this simple system as $(M + m/3)$

one third of its mass to that of the mass supported by the spring.

In many applications, particularly in control systems, the mass of the spring m is comparable with the supported mass M, and in these circumstances it is not sufficiently accurate to take the equivalent mass M_1 as $(M + \frac{1}{3}m)$. A method of dealing with this particular case is given below.

Consider a simple helical spring, made of wire of circular cross-section, which is clamped at one end and carries a mass M at the other. The equation of motion of the system may be written as

$$(M + km)\ddot{e} = -c^2 e \qquad \ldots (1)$$

where $c^2 = \dfrac{\pi G d^4}{8 l D^2}$

and e = elongation of the spring
l = total length of the wire
d = diameter of the wire
G = modulus of rigidity of the material
D = diameter of the helix
k = a constant, which Rayleigh's method gives as $\frac{1}{3}$

Putting $M + km = M_1$, then the frequency of vibration F is given by

$$F = \frac{1}{2\pi}\sqrt{\left(\frac{c^2}{m_1}\right)}$$

$$= \frac{1}{2\pi}\sqrt{\left(\frac{\pi G d^4}{8 l D^2 (m+km)}\right)} \qquad \ldots (2)$$

If, on the other hand, the equation of motion is written in the form usually associated with a continuous distribution of mass, we have

$$\frac{\partial^2 e}{\partial t^2} = \frac{c^2 L^2}{m} \cdot \frac{\partial^2 e}{\partial x^2} \qquad \ldots (3)$$

where L = axial length of the helix. The boundary conditions are $e = 0$ when $x = 0$. When $x = L$

$$M\ddot{e} = -c^2 L \frac{\partial e}{\partial x}$$

A solution of equation (3) which satisfies this first conditions is

$$e = A \sin \eta x \, \xi^{iat} \qquad \ldots (4)$$

where $\eta^2 = \dfrac{a^2 m}{c^2 L^2}$

From the second boundary condition

$$\tan \eta L = \frac{c^2 \eta L}{M a^2} = \frac{m}{M}\left(\frac{1}{-}\right) \qquad \ldots (5)$$

and the expression for frequency becomes

$$F = \frac{\alpha}{2\pi} = \frac{1}{2\pi} \cdot \frac{\eta L}{\sqrt{m}}\sqrt{\left(\frac{\pi G d^4}{8 l D^2}\right)} \qquad \ldots (6)$$

Equating (2) and (6) we have

$$k = \frac{1}{\eta L} - \frac{M}{m} \qquad \ldots (7)$$

and using (5) and (7) we may directly relate k to M/m.

This is shown in Fig. 7, from which it is clear that the particular value of

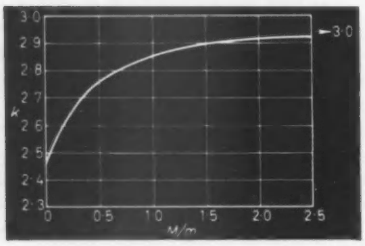


Fig. 7 A graph of k against M/m

$k = 3$, derived by the Rayleigh method, is the limiting value for $M/m \to \infty$

This factor is important in calculations on lightly loaded spring systems, i.e. where the spring mass is not small compared with the load. The above method of calculation would appear to be applicable to a wide range of spring systems, and the helical spring merely serves as a convenient example: it will also apply to the construction of an electrical analogue of a given mechanical system.

A new approach to magnets (*contd.*)

J. THILLAIMUTHU

4. Simple and effective focusing device in electron optics, for cathode ray tubes in television and radar, particularly in the latter eliminating complicated focus correction for astigmatism.

5. Precision solenoids (a.c. and d.c.) with sharp cut-off enabling axial positioning of plunger to within 0·0002 in. without mechanical stops giving higher pull/weight ratio and self-screening. The axial positioning accuracy is determined by the mechanical accuracies to which the solenoid and core are made (Fig. 2).

As these discoveries came out of the work on the electromagnetic computing element mentioned it is pertinent to state its operation. The unit is essentially a multiplying device to indicate, as a voltage analogue, the product of two variables—speed of rotation and displacement; and in construction it is a special form of an a.c. tachogenerator. The permanent magnet rotor slides axially on the shaft between a wound stator and a dummy stator. The flux is, so to speak, transferred to the stator from the store in the dummy stator as required. The problem was to get an even axial distribution of flux in the airgap without fringing losses etc, at the ends, for linearity of output, and elimination of zero errors.

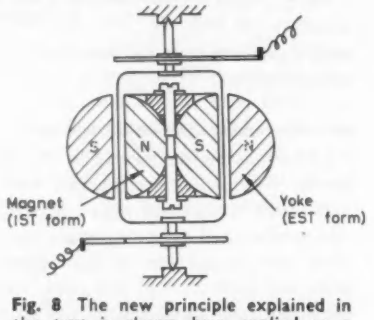


Fig. 8 The new principle explained in the text is shown here applied to a moving-coil meter movement

Working with a narrow airgap and a cylindrical magnet (4-pole), some degree of accuracy was achieved, but there was a residual voltage when the magnet was in the zero position, the resulting inaccuracy extending only for the first 5% of travel 0·05 in.). In trying to correct this apparently insignificant error various changes were carried out, amongst these was modifications to magnet shape. The cylindrical magnet had an axial bore for the shaft; rounding the bore on either side till the radii met inside the bore completely removed the zero error and improved the linearity. The dramatic find was that the magnet was reduced to the shape of the inner half of a toroid (IST).

Associating this discovery with that of the uniqueness of the toroid in magnetism it was argued the external half of the toroid (EST) should have

equally interesting and unsuspected properties—which were confirmed later by experiment.

. . . to LEVEL

A solution to last month's problem

The problem that we put forward to readers last month had apparently been solved many years ago by Isotope Developments Ltd. They produced a portable level detector for closed cylinders in response to enquiries from the fire fighting equipment industry. The detector is completely external and consists of two parts, an adjustable yoke which fits around the cylinder to be measured and an indicating unit. On one arm of the yoke is a radioactive source and on the other is the detector head. The yoke is moved down the cylinder, and as it passes the interface of the gas and the liquid a change occurs in the signal from the detector head. With cylinders up to 10 in. diameter and thicknesses up to $\frac{1}{2}$ in. the level can be checked to an accuracy of about $\frac{1}{4}$ in.

. . . to COMPUTERS

The digital differential analyser

D. F. WALKER, Ferranti

The general growth and development of computers has been broadly along two distinct channels, digital and analogue. Digital computers have mainly been designed as general purpose calculators carrying out discrete operations on quantities, such as addition and multiplication. Analogue computers, on the other hand, have been applied to more specialized problems in which the calculations are of a continuous nature with a real time significance. Because they rely on physical analogues, their accuracy is limited to 0·01% order.

The question at once arises—why not programme a general purpose computer to simulate these problems where greater accuracy is required? The reason for not doing this is simply that the programme would be far too time consuming and costly for most applications. A new type of computer called the digital differential analyser or incremental computer was developed for this purpose.

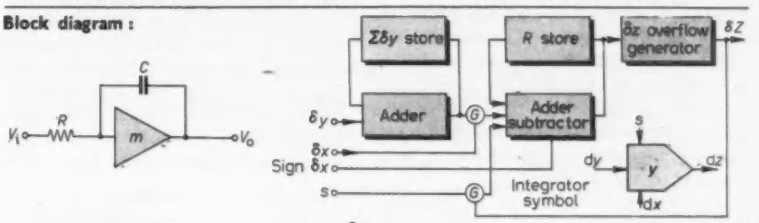
In order to give a better understanding of the basic element of the digital differential analyser, the digital integrator, an explanatory table has been drawn up showing the similarity between it and its analogue counterpart. A slight difference exists in the way the differential equations are broken up into standard integrating elements. In analogue computers the elements are chosen so that the absolute value of the integral is transferred between the various units (Figs. 1a and 2a), whereas in the digital method standardized incremental pulses interconnect and control the operation of the units (Figs. 1b and 2b). Digital integration is carried out by dividing up the independent variable into these standardized digital steps (Fig. 4b), taking the sum of the ordinates as the approximation for the integral and converting it back into standardized digital pulses by the overflow process (Fig. 3b). This summation is carried out by each dx digital pulse opening a gate which allows the ydx increments to be accumulated in the R store (Fig. 1b); thus each + ve dx pulse adds y to the contents of the R store while each − ve dx pulse subtracts y from the R store. When the value of the R store goes outside the range 0 to s, a dz overflow pulse is generated. The sign of this pulse is such that the subtraction of sdz from the R register brings it back within the range 0 to s. The dz incremental pulses, as well as being accumulated in a following integrator are also used to initiate any integration which has to be carried out with respect to z.

This carry overflow generation is exactly analogous to that used in the addition of numbers where s represents one of the radices of a system. Suppose it is required to integrate the area under the curve in Fig. 4b to the nearest square foot, where y and x are in inches. The area would then be represented in the following integrator store which is fed with dz incremental square foot pulses and the remainder would be stored as square inches in the R register. If an incremental area ydx square inches is added to R, bringing it above the value 144, a positive square foot carry is generated and 144 is subtracted from the R register. Alternatively, if ydx is negative and causes R also to go negative, a negative square foot carry is generated, one is borrowed from z and 144 is added to the contents of R.

to be continued

ELECTRONIC ANALOGUE INTEGRATOR	DIGITAL INTEGRATOR

Block diagram:



1a 1b

Simulated equation:

$$V_o = \frac{1}{RC}\int V_i\,dt \qquad dz = \frac{ydx}{s}$$

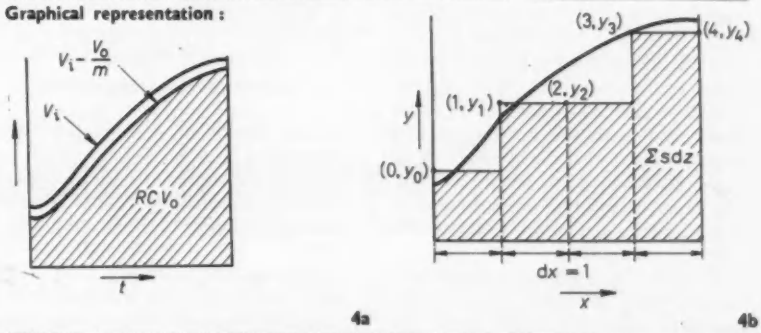
2a 2b

Simulated approximation:

$$V_o = \frac{1}{RC}\int V_i\,dt - \frac{1}{RC}\int \frac{V_o}{m}\,dt \qquad \Sigma sdz = y_0.1 + y_1.1 + y_2.1 + y_3.1$$

3a 3b

Graphical representation:



4a 4b

New for Control

A monthly review of system components and instruments

LEVEL CONTROLLER

the first of its kind

The Leveltron industrial proximity switch is claimed to be the first with continuously variable differential control. The controller is capacitance-operated, and the differential range can be set between 1 and 40 $\mu\mu$F by the adjustment of two controls. The first sets the control point of the relay. The second then varies the reset point without affecting the setting of the control point, and so fixes the differential.

The control point drift is less than 1 $\mu\mu$F over a period of 3 months, given steady supply voltage and temperature; less than ± 1 $\mu\mu$F for 10 to 15% variations in supply voltage; and less than 1 $\mu\mu$F for ambient temperature changes from 0–40°C. The differential drift is less than $\pm 0{\cdot}5$ $\mu\mu$F over a period of 3 months given steady supply voltage and temperature; $\pm 0{\cdot}5$ $\mu\mu$F for 10 to 15% variations in supply voltage; and less than 0·5 $\mu\mu$F for ambient temperature changes from 0–40°C. Variations resulting from humidity are negligible.

Measurement is possible up to 180 ft from the point of detection. Models are available to work on 110, 240 or 440 V a.c. 40–60 c/s. The basic instrument has a switching capacity of 5 A (non-inductive) at 250 V a.c., but in the heavy industrial model this is increased to 10 A (non-inductive) at 250 V a.c.

The Leveltron is made by Thomas Industrial Automation Ltd. The prices range from £26 to £46 per instrument and the delivery varies from 1 to 3 weeks.

Tick **No 200** on reply card

POTENTIOMETRIC RECORDER

addition to an existing range

Increased facilities are announced by Sunvic Controls Ltd. for their high-speed potentiometric recorder. Single trace and 2, 4, 8 or 16 point multi-trace instruments are now available, with standard facilities consisting of any one of 13 different input units and a choice of three different chart drive gearboxes. Additional facilities include alarm and control contacts, solenoid pens, retransmitting slidewire, a digitizer and fast/slow speed recording timer.

The input units include four millivolt pattern with plug-in range change assembly, alternative scale spans and either with or without zero shift. There is a choice of eight temperature inputs with alternative scale spans, automatic cold junction compensation or external reference, and four-position range switch or miniature range-change relays with or without zero suppression. Alternatively a high impedance input unit can be supplied.

Chart drive gearboxes are of the lever-change type giving 27 different chart speeds varying from 1 in./h to 3 in./min.

Recorders are normally supplied with a constant current supply unit which has an accuracy of $\pm 0{\cdot}1\%$ over a 1000 h period. Instruments can be supplied with a speed of response of 1 sec, a guaranteed calibration accuracy of $\pm 0{\cdot}5\%$ f.s.d. and (for high impedance instruments) a sensitivity of $\pm$ 0·25% at 10M ohms with a scale span of 15 mV.

Tick **No 201** on reply card

TRANSISTOR BETA TESTER

a low priced equipment

The transistor beta tester introduced by Siemens Edison Swan Ltd. is described as the first low priced (£11) transistor tester on the market. It provides quick, accurate, run-of-the-mill tests on all *p-n-p* transistors, current gain and collector leakage being measured under common emitter conditions. Current gain (10–150)

Battery-operated, transistorized

is read directly off a calibrated dial in conjunction with an audible signal at a collector current of 0·5–4 mA. Leakage current is measured on a meter at a fixed collector voltage of 9 V. Accuracy is $\pm 5\%$.

The new beta tester is a battery-operated transistorized unit in a die-cast alloy case. The terminals are of the quick-release type. Measurements can be carried out by unskilled personnel in a few seconds.

Tick **No 202** on reply card

THERMOCOUPLE WIRE

outside dia. of only 0·5 mm

A miniature thermocouple wire with an outside diameter of 0·5 mm is the latest addition to the Thermocoax range of ceramic-packed thermocouple wires distributed in the UK by Research and Control Instruments Ltd. Known as the Thermocoax 2AB Ac 05, it has an outer sheath of 18/8 steel and cores of chromel/alumel insulated from each other and the sheath by powdered magnesium oxide.

Temperature range is stated to be 0–900°C and an accuracy of 2·8°C up to 350°C and of 0·75% from 350°C to 1000°C is claimed together with good stability, short response time, great mechanical strength, and excellent electrical insulation. It may be bent on a radius of 1 mm. A new 1 mm Thermocoax with Inconel sheathing is also available with greater resistance to corrosion than the standard 18/8 steel sheath type. Another innovation is a box of accessories for facilitating the correct forming of thermocouples and for protecting the couple itself against corrosion.

Tick **No 203** on reply card

QUICK LOOKS

• The Grampian low frequency amplifier has been designed to drive vibration test generators and similar equipment, where large outputs at low frequencies are required. The output power is 100 W r.m.s. continuous sine wave rating at 10 c/s to 5 kc/s. The output impedance is variable from 10 to 100 ohms, with an input impedance of 10 kilohms.

Tick **No 204** on reply card

• Marconi Instruments have shown a circuit magnification meter (TF1245). This is a single Q-meter covering a range a.f. to v.h.f. (1 kc/s to 300 Mc/s). It permits direct measurement of Q-factors from 5 to 1000.

Tick **No 205** on reply card

• In their electric motor control gear intended for industrial or other timing

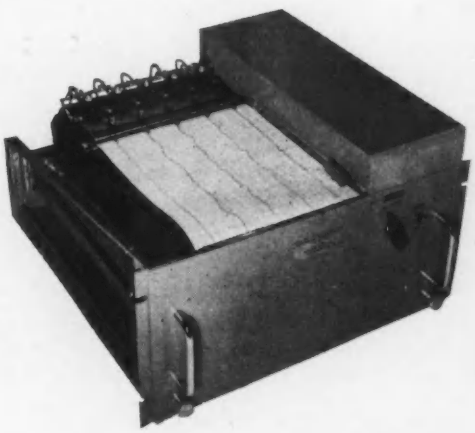
CAPTURE

TRANSIENT PHENOMENA FOR GOOD WITH

High-speed

PEN RECORDERS

Continuous recording of rapid, transient or oscillatory phenomena is made possible with Kelvin Hughes High Speed pen recording instruments. A wide range of instruments is available including new units which will permanently record up to 8 variables simultaneously. When used in conjunction with special Kelvin Hughes bridge amplifiers and power units, the recorders will measure strain, force, displacement, drag, pressure, acceleration and similar variables, providing instantaneous permanent recordings. Rapid response, versatility and dependability make them well suited for research work in aerodynamics, rockets, hydraulics, computers, and countless applications in industry, including civil engineering, mining, production testing of motor cars and tractors.



Ruggedly built and insensitive to external vibrations, Kelvin Hughes pen recorders will operate effectively under the most exacting conditions in vehicles, aircraft, and where heavy industrial plant is operating.

Please write for technical literature. Kelvin Hughes specialists are freely available to advise on any particular application for single- or multi-channel recorders in industry.

KELVIN HUGHES

SPECIALISTS IN INDUSTRIAL MEASUREMENT

KELVIN & HUGHES (INDUSTRIAL) LTD., KELVIN HOUSE, WEMBLEY PARK, MIDDX

60-72 Kelvin Avenue, Hillington, Glasgow, S.W.2

applications Brook Motors Ltd. have incorporated an electronic time delay unit of their own design. It is suitable for use with start-to-run motor switching on hand-operated starters, slip ring automatic starters, motor braking periods, sequence starting and stopping, and process control timing and cycling.
Tick **No 205** on reply card

• An addition to their range of plug-in precision limit switches has been made by Square D Ltd. The new switch (type AW-36) has roller plunger actuation with micro adjustment, which allows positioning over a ½ in. range.
Tick **No 206** on reply card

• An improved speed regulator has been produced by Baldwin Instrument Co. Ltd. It is available in ¼, ½, ¾ and 1 in. bore sizes, and the maximum working pressure is 150 lb/in.².
Tick **No 207** on reply card

• A range of Philips automatic conductivity measurement equipment permitting continuous recording and control of the strengths of process solutions is being distributed in the UK by Research and Control Instruments Ltd. The equipment is made in Holland by N. V. Philips Gloeilampenfabrieken.
Tick **No 208** on reply card

• A miniature high-speed electromagnetic counter from the Dependable Relay Co. Ltd. is available in two models. The standard model 1500 has a maximum counting rate of 1500 counts/min. It is complete in a box with an outlet for a photoelectric cell or similar unit, and can be supplied for a.c. mains or 12 V d.c. operation. The model 3000 has a counting rate of 3000 counts/min, but is otherwise as standard. Other models have 5-figure manual reset but can be provided with batch counting and electrical reset facilities.
Tick **No 209** on reply card

• Two new units are available from Plessey Nucleonics for polarizing ionization chambers used in the flux measuring channels of nuclear reactor instrumentation systems. The H.T. output, from 400 to 600 V, is derived from a transistor converter circuit and an alarm relay is provided which indicates failure of output or disconnexion.
Tick **No 210** on reply card

• An instrument rack from Imhofs has been designed to carry simultaneously equipment fitted with British, American or Continental fixings. It is known as the Imrak, international series, and packs conveniently flat.
Tick **No 211** on reply card

• A quick-acting coupler with an inlet thread of ¼ in. has been added to Schraders' heavy duty range. The rate of free air flow through the coupler is approximately 100 ft³/min at 100 lb/in.² inlet pressure.
Tick **No 212** on reply card

• The Diesindicator is the latest addition to the range of diesel engine service equipment manufactured by Dunedin Engineering Co. Ltd. It has been designed to register accurate peak and initial cylinder pressures upon a 2000 lb/in.² dial gauge. It is suitable for low, medium and high speed diesel engines where access to the combustion chamber is provided.
Tick **No 213** on reply card

• A 5-terminal illuminated press switch has been announced by the Aircraft Components Division of Thorn Electrical Industries Ltd. This compact switch uses an Atlas midget panel lamp, and the incorporation of the 5-terminal arrangement enables it to be supplied in thirty-four circuit variations.
Tick **No 214** on reply card

This marine chronometer by Sperry Gyroscope Co. Ltd. has an accuracy of 1 part in 2 million or 15 sec a year. The instrument uses a quartz crystal. Transistors and printed circuits have been used to make it compact
Tick **No 215** on reply card

• Sarkes Tarzian Rectifier Division have announced the addition of the H series to their low current silicon rectifier family. The series features the top-hat package, heavy duty junction and hermetic sealing. The d.c. current rating is 750 mA to 55°C and the voltage range is from 100 to 600 V peak inverse.
Tick **No 216** on reply card

• A 3-phase supply monitoring relay, developed by Lancashire Dynamo Electronic Products Ltd., is designed to provide protection against complete failure of one, two or three phases of a 380/440 V 3-phase supply. The unit also includes facilities to provide a signal when any phase voltage is reduced to between 80 and 95% of nominal voltage. At any set point in this range, the protective relay will operate when the voltage falls to within ±1% of the set level.
Tick **No 217** on reply card

INDUSTRIAL PUBLICATIONS

The well produced 156-page 1958 **Annual Report** of the British Iron and Steel Research Association, lists reports, members, committees and their work, and other useful reference information.
Tick **No 218** on reply card

'Your Control Problems' sets out briefly, the application of Sperry Gyroscope's **standard components** to three types of problems, viz positional and speed control, and copying systems.
Tick **No 219** on reply card

A comprehensive English/German brochure on their **dynamic analysis instruments** from Solartron.
Tick **No 220** on reply card

Two other Solartron publications are **Precision electronic instruments** and **Datatape.**
Tick **No 221** on reply card

Smart brochure from the Morgan Crucible Co. Ltd. illustrating their **carbon brushes.**
Tick **No 222** on reply card

From Craven Electronics Ltd. a **catalogue** covering a range of electronic equipment.
Tick **No 223** on reply card

Negretti & Zambra have now issued their general catalogue in **Portuguese.**
Tick **No 224** on reply card

News sheet concerning **Wheelco instruments** manufactured by Barber-Colman Co.
Tick **No 225** on reply card

Brochure entitled 'Semiconductors' briefly surveys the uses of **semiconductor devices** and some possible future developments—Johnson, Matthey & Co. Ltd.
Tick **No 226** on reply card

ASEA catalogue describing an **electrohydraulic governor** for water turbines which produces all control quantities electrically, and uses hydraulic servos to provide power amplification.
Tick **No 227** on reply card

Johnson, Matthey & Co. Ltd., four electrical engineering **data sheets** on germanium, pure metals, alloys, salts and anodes for semiconductor devices.
Tick **No 228** on reply card

May supplement to the Radiospares April catalogue lists **lampholders, polythene and screened wires,** etc.
Tick **No 229** on reply card

A stencilled Ferranti booklet contains questions and answers on the **Sirius computer.**
Tick **No 230** on reply card

Read how the West Midlands Gas Board saved £40,000 in transport costs

Read how Belling and Lee do 3 weeks' work in 30 minutes

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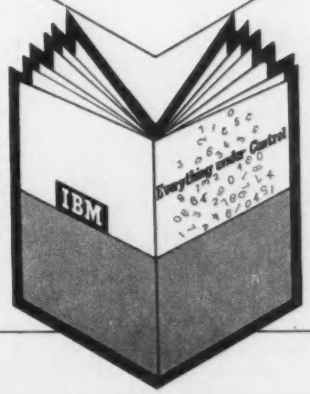

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For your bookshelf

Not the best but better than usual

Principles of Automatic Controls *by* **Floyd E. Nixon.** *Macmillan. 1958. 414 pp. 30s.* ★ 249

Control engineers are aware that the rapid developments taking place in process control, rocket satellites, machine tool controls, etc., are due to the excellent components available being used judiciously by control system designers. The technical knowledge required may be given to these designers when they are studying at a technical college; or they should be able to acquire it themselves after graduating in engineering science. The book presently discussed may be recommended as a study book both for the technical college student, and the good graduate engineer who wishes to study control engineering. There are better reference books for the practising engineer.

How many authors since Routh have written a thorough treatment of control system dynamics? There are a few exceptions, but usually, as in this book, the authors follow the treatment that would be expected in a good design office manual. The result is that the reader may obtain a sufficient knowledge of the design procedures adopted without really understanding the dynamics of a control system. The book gives the principles of automatic control system design omitting a detailed discussion of many fundamental theoretical aspects. However, the treatment is better than that usual in elementary textbooks.

The book covers the usual topics of automatic control: Laplace transforms, block diagrams, stability criteria and the methods of compensation used to improve transient response. There are good chapters on the Evans root-locus method, and the methods used for analysing transient response data. The author discusses more practical aspects of the subject as well. One chapter describes automatic computers, digital computers being touched on and a good introduction given to analogue computers. The first chapter is very interesting—particularly the control system which automatically maintains a desired level of anaesthesia for a patient undergoing an operation. An extensive table of Laplace transform pairs is included.

The present text appears to have been litho-printed, without any change, from the original version published in the USA by Prentice-Hall. The print has a flat, slightly fuzzy look which is not inviting to the eye. J. V. PARRY

High-power approach

Position Control of Massive Objects *by* **Prof. A. Tustin** *et al. Supplement (No. 1) to Part C of the Proceedings of the Institution of Electrical Engineers. 1958. 64 pp. 15s.* ★ 250

These two papers contain a detailed examination of the design of high-power position-control systems leading to an effective method requiring a minimum of trial and error.

Although the first paper deals with a design procedure for a well-defined class of position servomechanisms, namely those employing rotating or magnetic amplifiers, the thorough discussion of specifications and of phase utilization functions is of general interest.

Section 1 describes constraints on the form of the log-gain/log-frequency characteristics resulting from torque and speed limitations, the effect of noise on saturable elements, the variability of components and the need to provide smooth operation at very low speeds. This leads to a discussion of generator and motor stages and the relationship between their time-constants and their power gain. Stages with and without feedback are considered. Selection of machine elements using the phase utilization function as a criterion of merit is described in the next section. Sections 4 and 5 deal with the design of modifying networks for insertion in thermionic stages and feedback in machine stages. A brief discussion of physical construction and limitations in the design follows. Some aspects of design which require further investigation are suggested in the concluding remarks.

The results obtained in the paper can be generalized by applying the concepts of dimensional analysis which form the subject of the second paper. Having discussed the fundamental theorems, the author considers dynamic similarity of linear systems and the effect of feedback. He points out that the structure of equations as well as dimensions of the quantities is involved when feedback exists. Conditions for dynamically similar behaviour of non-linear systems are briefly discussed.

Dimensional analysis is a powerful tool. It must however, be used with care or mathematical manipulations of non-dimensional groups may result in physically meaningless equations, particularly when these groups are used to describe process plant dynamics. While it may not be possible to apply directly the procedures developed in these papers to solution of control problems in related fields, it may prove helpful to adopt the approach described by the authors in tackling such problems. T. B. JAWOR

Samples on ice

★ 251

Sample Data Control Systems *by* **Eliahu I. Jury.** *John Wiley & Sons: New York. Chapman & Hall: London. 1958. 468 pp. £6 8s.*

Here is another excellent book on the subject of sampled data control systems. Since Dr. Jury spent some time at Columbia University it is not surprising that this book has a certain affinity for the one by Ragazzini and Franklin.* However, the two books are by no means overlapping and Dr. Jury's includes much original material.

If there is any fault, it is one common to most texts on sampled data systems, namely the rather formal, cold way in which much of the material is set down. One gets the impression that too much effort has been made to 'programme' the work. This produces a somewhat frigid atmosphere and makes it rather difficult for the newcomer into the field. What appears to be needed is a less formal type of book, discussing, without too much rigorous detail, the broad aims, design techniques and equipment of sample data systems. While Dr. Jury's book is not intended to meet this need it certainly is a valuable work. One of its chief assets is its extensive tables of transforms and system configurations These make it particularly useful as a designer's reference book.

The mathematical treatment is precise and formal, but shows little of the personality of the author. The text covers the definition and properties of the Z transform, and its modifications. Their application to the analysis and synthesis of sampled data systems is discussed in detail. Worth special mention are the chapters dealing with the physical realization of digital compensators and with finite width pulses. J. M. NIGHTINGALE

*Reviewed in CONTROL, December 1958, p. 308

Books received

Electronic Engineers Reference Book 2nd Edition by L. E. C. Hughes. Heywood & Co. 1959. 1588 pp. £4 4s. ★ 252

Electronic Digital Computers by Charles V. L. Smith. McGraw-Hill. 1959. 443 pp. £4 13s. ★ 253

High Speed Computing — Methods and Applications by S. H. Hollingdale. English Universities Press. 1959. 244 pp. £1 5s. ★ 254

Basic Electronics by J. Daly and R. A. Greenfield. Heywood & Co. 1959. 226 pp. £2 5s. ★ 255

Magnetic Amplifier Engineering by G. M. Attura. McGraw-Hill. 1959. 220 pp. £2 18s. ★ 256

Noise in Electron Devices by L. Smullin and H. Haus. John Wiley. 1959. 413 pp. £4 16s. ★ 257

Multivibrator Circuits by A. H. Bruinsma. Cleaver-Hume Press Ltd. 1959. 65 pp. 9s. 6d. ★ 258

Practical Robot Circuits by A. H. Bruinsma. Cleaver-Hume Press Ltd. 1959. 125 pp. 17s. 6d. ★ 259

Science News 52 edited by Archie and Nan Clow. Penguin. 1959. 128 pp. 2s. 6d. ★ 260

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